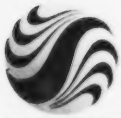

Stantec

# ALBERTA ENVIRONMENT WATER FOR LIFE - AQUATIC ECOSYSTEMS REVIEW OF ISSUES AND MONITORING TECHNIQUES

October 2005

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ALBERTA ENVIRONMENT
WATER FOR LIFE – AQUATIC ECOSYSTEMS
REVIEW OF ISSUES AND MONITORING TECHNIQUES

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# 1.0 Introduction

## 1.1 BACKGROUND

Water for Life: Alberta's Strategy for Sustainability, released in November 2003, identifies healthy aquatic ecosystems as one of its three main goals. The water strategy outlines several short, medium and long-term actions that are necessary in order to succeed in achieving this goal. One short-term action is to 'develop a system for monitoring and assessing aquatic ecosystems'.

To fully utilize the knowledge already derived from the monitoring and assessment of aquatic ecosystems in Alberta, and to optimize its use as a basis for an integrated and comprehensive aquatic ecosystem monitoring program, it is necessary to determine which approaches will provide the most reliable measures of aquatic ecosystem health. It is also necessary to evaluate issues that are of current or potential future concern for aquatic ecosystem health in Alberta.

Issues of concern in Alberta include, for example, the effects of agriculture, resource exploitation, industrial development, forestry, dam and reservoir construction, hydro-electric development, city/municipal developments, industrial and agricultural growth, population growth and climate change. These issues can provide a wide variety of stressors that affect aquatic ecosystems. Stressors include physical, chemical and biological factors that are either unnatural events or activities, or natural to the system but applied at an excessive or deficient level. Stressors can cause significant changes in the ecological components or receptors in the aquatic ecosystem.

## 1.2 GENERAL OBJECTIVES

The general objectives of this study were:

- to review current and future issues that represent a concern for aquatic ecosystem health; and
- to review, evaluate and prioritize techniques available for monitoring and assessing aquatic ecosystem health.

## 1.3 STUDY APPROACH

A great deal of effort by the scientific community has gone into defining the term "aquatic ecosystem health". The definition of what ecosystem health actually is, are many and varied. Since the definition of health is constantly evolving, a working definition of "aquatic ecosystem health" was developed as part of this study.

A review of issues which are recognized as a threat to aquatic ecosystem health in Alberta was conducted as follows:

- A literature review of aquatic ecosystem studies was conducted to determine aquatic ecosystem health issues of concern in Alberta. Information was also obtained from the "inventory of aquatic monitoring and research program" study, which held interviews with various groups and organizations to provide a range of potential issues (Stantec 2005).
- A description of the nature of effects on aquatic ecosystem health for each issue was determined based on the specific type of effect, which biotic community or abiotic characteristic is being affected, what may cause the effect, and the sensitivity and requirements of the aquatic ecosystem. These issues were then prioritized based on their potential severity in Alberta.

A review and evaluation of techniques available for monitoring and assessing aquatic ecosystem health was conducted as follows:

- A literature review of aquatic ecosystem health assessment techniques was conducted to provide a description of the various techniques available. A search for techniques was made from studies conducted in Alberta, other provincial jurisdictions and nationally. Techniques included aquatic ecosystem indicators and assessment tools that are used for assessing flowing and standing waters.
- The various assessment techniques and monitoring tools were evaluated and rated with respect to their relevance to Alberta ecosystems, the identified issues of concern, their stature and acceptance in the discipline, their effectiveness to assess the issues, and their practicality.

# 2.0 Aquatic Ecosystem Health Definition

## 2.1 BACKGROUND

An ecosystem is an ecological community, including living organisms, together with their physical and chemical environment, functioning as a unit. Aquatic ecosystems include the full diversity of rivers, streams, lakes and wetlands, as well as riparian areas and groundwater systems that are linked to them. Aquatic ecosystems provide important ecological services, cultural, heritage and scientific values, rich diversity of plant and animal life, and support a variety of human uses, such as fisheries and recreation (Alberta Environment 2005a).

The concept of "ecosystem health" can be difficult to define particularly since the term "health" can be viewed in a variety of ways. A great deal of effort has gone into defining the term ecosystem health and the definitions of what ecosystem health actually is, in terms of a precise and practical definition, are many and varied. The definition of health is constantly evolving and the social context strongly conditions what is considered to be healthy.

The term "health" comes from a Germanic root meaning whole or uninjured. The dictionary defines "health" as a flourishing condition, well-being, vitality or prosperity (Oxford English Dictionary 1971, Websters New Collegiate Dictionary 1974).

The concept of health needs to be extended from its traditional levels of the individual and population to that of the whole ecosystem (Rapport *et al.* 1999). This involves the development of methods of assessing the degree to which the functions of complex ecosystems are maintained or impaired by human activity. It also involves formulating new strategies that take account of societal values and biophysical realities to manage human activities so that ecosystem health is enhanced and not compromised further (Farnsworth 1995, Vitousek *et al.* 1997, Gaudet *et al.* 1997, Cairns 1998).

The concepts within the framework for studying ecosystem health have their greatest potential for applicability in addressing environmental problems only if the biophysical basis for life (including human) and its abundance, diversity and activity are placed front and foremost (Belaoussoff and Kevan 2003). For conservation and environmental sustainability to be achieved the public must come to understand the importance of ecological principles to their own immediate and long term well-being (Belaoussoff and Kevan 2003),

Ecosystem health has been subject to much debate in the scientific literature about its desirability or utility (Calow 1992, Callicott 1995, Wicklum and Davies 1995, Scrimgeour and Wicklum 1996, Meyer 1997). The difficulties come from a reluctance to use a term such as health that clearly implies to an evolved state for an individual but not for an ecosystem. It is not clear which changes in an ecosystem represent a decline in health or even what characterizes good health (Fairweather 1999), although recognizing a lack of health is considerably easier (Rapport *et al.* 1985, Rapport *et al.* 1999). Rapport (1989) suggests that efforts to protect

ecological health must consider the human uses and amenities derived from the system. Regier (1993) and Meyer (1997) agree with the importance of societal values in defining and protecting health.

Philosophically the term health is useful because it is readily interpreted by the general public and evokes societal concern about human impacts on ecosystems (Boulton 1999). Karr (1999) suggests that health as a word and concept in ecology is useful precisely because it is a concept all people are familiar with. Karr (1999) describes "health" as "good condition". However, the term must be 'operationalized' (i.e., defined and ways found to measure it), but as a policy goal, the protection of the health and integrity of our landscapes and rivers has at least some chance of public interest and support (Karr 1999). Protecting biological or ecological integrity is the core principle of various Acts (e.g., United States Clean Water Act, Canada's National Park Act, and the Great Lakes Water Quality Agreement between the United States and Canada). Words like health and integrity are embedded in these laws because they are inspiring to citizens and a reminder to those who enforce the law to maintain a focus on the big picture, the importance of living systems to the well-being of human society. We can define health and integrity in ways that will operationalize the terms, using them to help us understand humans' relationship with their surroundings (Karr 1999).

In contrast to definitions of healthy ecosystems based on solely ecological criteria (Haskell *et al.* 1992) judgements of river health must include human values, uses and amenities derived from the system (Rapport 1989, Rapport 1995, Steedman 1994, Meyer 1997, Fairweather 1999, Karr 1999). Karr (1999) and Meyer (1997) incorporate ecological integrity (maintaining ecosystem structure and function) and human values (what society values in the ecosystem) into the definition of river health. Ecological criteria include sustainability, resilience to stress and ecological integrity – the capacity to support and maintain a balanced, integrated, adaptive biologic system having the full range of elements and processes expected in the natural habitat of a region (Karr 1996).

When human activities within a watershed are minimal, the biota is determined by the interaction of biogeographic and evolutionary processes in the regional climatic and geological context (Karr 1999). As human populations increase and technology advances, landscapes are altered in a variety of ways. Those changes alter the waterbody's biota and thus the entire biological context of the waterbody, causing it to diverge from integrity (Karr 1999). In some cases, the changes are minor, while in others, they are substantial, even eliminating all or most of the plants and animals. Wetland health, which is land transitional between aquatic and terrestrial ecosystems, has been defined as the ability of the system to perform certain wetland functions (Cows and Fish 2005a, 2005b, WHEP n.d.). These functions include filtering pollutants, sediment trapping, shoreline maintenance, water storage, aquifer recharge, primary biotic production and habitat for various biota. Riparian health is similarily determined by its ability to perform certain ecological functions including trapping and storing sediments, maintaining banks and shores, storing water and energy, recharging aquifers, filtering and buffering water, reducing energy, maintaining biodiversity and creating primary productivity (Ambrose *et al.* 2004). Healthy riparian habitat helps to protect wildlife and plant species,

improves fish habitat, provides runoff and erosion control and improves the quality of surface waters (Manitoba Riparian Health Council n.d.)

The approach proposed by the Northern River Basins Study (NRBS) is to recognize that the perception of health will vary with each ecosystem and over time (Alberta Environment 1996). This strategy proposes that the desired structure and function of the ecosystem being managed will arise through a process that combines the best available scientific knowledge with societal expectations and concerns.

## 2.2 DEFINITION

A large number of definitions for a healthy ecosystem have been proposed and most share common elements.

Haskell *et al.* (1992) and Costanza (1992) provide a working definition of ecosystem health: it is healthy "if it is active and maintains its organization and autonomy over time and is resilient to stress". Mageau *et al.* (1995) indicate that a healthy ecosystem has three main features – vigor (productivity), resilience and organization. These definitions emphasize the ecological aspects of ecosystem health.

According to Karr *et al.* (1986) a biological system can be considered healthy when its inherent potential is realized, its condition is stable, its capacity for self-repair when perturbed is preserved and minimal external support for management is needed. Karr (1999) equates health with terms such as self-organizing, resilient and productive. Ecological criteria include sustainability, resilience to stress and ecological integrity – the capacity to support and maintain a balanced, integrated, adaptive biologic system having the full range of elements and processes expected in the natural habitat of a region (Karr 1996).

Rapport *et al.* (1999) take into account the human health dimension. Ecosystem health comprises "a systemic approach to the preventive, diagnostic and prognostic aspects of ecosystem management, and to the understanding of relationships between ecosystem health and human health". A healthy ecosystem is an environment that maintains biodiversity, is relatively stable and is resilient to change (ability to recover from disturbance) (Rapport *et al.* 1995). An essential component of health is the capacity to achieve reasonable human goals (meeting needs) (Rapport *et al.* 1999). This along with the capacity for renewal (i.e., maintaining organization including resilience, vigor, etc.) is the essence of health.

Meyer (1997) also incorporates the human aspect into the definition: "a healthy ecosystem is sustainable and resilient, maintaining its ecological structure and function over time while continuing to meet social needs and expectations". This concept explicitly incorporates both ecological integrity (maintaining structure and function) and human values (what society values in the ecosystem).

A working definition of "aquatic ecosystem health" was developed as part of this document, mainly on the ideas that incorporate both ecological integrity and human values (Meyer 1997, Karr 1999, Rapport *et al.* 1999).

*"A healthy ecosystem is sustainable and resilient to stress, maintaining its ecological structure and function over time similar to the natural (undisturbed) ecosystems of the region, with the ability to recover from disturbance, while continuing to meet social needs and expectations ".*

## 2.3 GLOSSARY

This glossary provides definitions for the terms used to describe aquatic ecosystem health.

| | |
|---|---|
| Biodiversity | The variety and variability among living organisms and the ecological complexes in which they occur and it encompasses different ecosystems, species, genes and their relative abundance. |
| Ecological Integrity | The ability of the physical, chemical and biological components of an ecosystem to support and maintain a balanced, adaptive community of organisms having a species composition, diversity and functional organization comparable to that of natural ecosystems within a region. |
| Organization | There are structural and functional relationships between system components that provide some degree of integration or organization. Structure refers to the physical organization or pattern of a system (i.e., the way in which parts are arranged or put together to form a whole). Function refers to ecological and evolutionary processes. |
| Receptors | An ecological entity that reacts to or is influenced by environmental stressors. |
| Resilience | The ecosystem's capacity to maintain structure and function under stress and the ability to recover from a disturbance. |
| Self-organizing | It refers to a process in which the internal organization of a system, increases automatically without being guided or managed by an outside source. In biology, it refers to the self-maintaining nature of systems from the cell to the whole organism. |
| Stressor | Physical, chemical and biological factors that are either unnatural events or activities, or natural to the system but applied at an excessive or deficient level, which adversely affect the ecosystem. Stressors cause significant changes in the ecological components, patterns and processes in natural systems. Examples include water withdrawal, pesticide use, timber harvesting, acidification, and land-use change. |

| | |
|---|---|
| Sustainability | The ability of an ecosystem to maintain ecological processes and functions, biological diversity and productivity over time. It is the ability to meet the needs of the present without compromising the ability of future generations to meet their own needs. |
| Vigor | Overall health. The capacity for healthy, natural growth and survival, and resistance to physiological stress. |

# 3.0 Review of Issues

## 3.1 APPROACH TO ISSUE IDENTIFICATION

Issues of concern in Alberta include, for example, the effects of agriculture, resource exploitation, industrial development, forestry, dam and reservoir construction, hydro-electric development, city/municipal developments, industrial and agricultural growth, population growth and climate change. Effects in aquatic ecosystems may not only directly affect aquatic organisms but may extend into semi-aquatic species. Similarly, effects are not solely related to biotic factors but may include abiotic effects that ultimately affect the aquatic ecosystem. These issues can be considered individually or more frequently in a synergistic or cumulative manner. One issue may dominate over another but cumulatively they all may contribute to effects on receptors in the aquatic ecosystem. These issues are broad in context and have a number of underlying or subset of issues related to them. In a number of instances there is a commonality and overarching of issues as well as the potential for synergistic effects. This may be best illustrated by the issue of climate change, which may be the result of the cumulative effect of a number of other issues such as resource exploitation, population growth and agricultural development.

Issues are based on survey results from a companion study (Stantec 2005), a literature review, input from Alberta Environment, and our general knowledge of the issues facing aquatic ecosystems in the province. The identified issues are presented in Table 1. The approach taken was to first categorize the issues into broad categories and then to develop a series of sub-issues around them. Some issues are common to several broader issues (such as contaminant loading, physical alterations, water use/allocation). This was followed by the identification of the specific concern or stressor for each issue. Although the source and loadings may differ, the receptor effects are similar in many cases, but the magnitude and geographic extent of the effect may differ.

For many of the stressors, there is an exhaustive amount of scientific literature on the receptor effects in or associated with aquatic ecosystems. However, for this report only a summary of recent literature is presented in order to provide an overview of the type of ecosystem effects that have been reported.

The distribution of the issue and its effects in Alberta is provided by indicating whether it is a province-wide issue or a local issue specific to a particular watershed or basin. Severity of effects was based on available published literature, survey data and our experience and understanding of known effects in aquatic ecosystems. The severity of effects on aquatic ecosystems in Alberta were categorized and defined as low, moderate, high or unknown (or emerging). The severity of effects was also defined in terms of the geographic distribution of the effect. Severity may be localized to a particular watershed or sub-basin and not necessarily apply in a regional or provincial context. The intent here is to attempt to prioritize issues that can then be transposed onto a local or regional scale.

**Table 1. Issues affecting aquatic ecosystem health in Alberta.**

| Issue | Specific concern (or stressors) | Type of effects on aquatic ecosystem health | Distribution in Alberta | Severity | | | |
|---|---|---|---|---|---|---|---|
| | | | | Low | Moderate | High | Unknown |
| **NATURAL RESOURCE EXPLOITATION** | | | | | | | |
| **Coal Mining** | | | Foothills/Battle River Drainage Basin | | | | |
| Point Source and Non-Point Source Contaminant Loading | Sediments | • clogging of substrate of fish spawning grounds<br>• reduced primary and secondary productivity | | | | locally | |
| | Metals | • potential bioaccumulation (selenium) and fish toxicity | | | locally | | |
| | Nutrients | • eutrophication<br>• cyanotoxins | | locally | | | |
| Landscape Changes (physical alterations) | Habitat alteration<br>Disturbance of hydrologic regime<br>End-pit lakes | • change from riverine to lacustrine environment (endpit lakes)<br>• disruption of natural groundwater-surface water interactions<br>• increased potential of leaching of metals (e.g., selenium)<br>• water quality impairment | | | | locally<br>locally<br>locally | |
| Water Management | Storage of selenium-rich water in endpit lakes | • potential bioaccumulation and (fish) toxicity (Se issue) | | | locally | | |
| Air Emissions | Dust and associated contaminants | • bioaccumulation of heavy metals in biota | | locally | | | |
| | Vehicle emissions (green house gases) | • indirect effects (green house gases- climate change) | | | | | locally |
| **Oil and Gas Exploration/Exploitation** | | | Province-wide | | | | |
| Point Source and Non-Point Source Contaminant Loading | Alteration of material fluxes to surface waters | • eutrophication | | locally/provincially | | | |
| | Chemical weed control | • increased flux of herbicides, possible impacts on biodiversity and foodchains | | locally/provincially | | | |
| | Saline water discharge | • water quality impairment | | locally/provincially | | | |
| Landscape Changes (physical alterations) | Network of cut lines | • easier access to remote water bodies and increased potential of excessive or irresponsible use (fisheries) | | | Green zone | locally | |
| Water Use /Water Allocation | Change in flow regime<br>Surface and sub-surface withdrawals (instream flow needs) | • habitat loss through reduced surface and base flows | | locally/provincially | | | |
| Biosolids/Sludge Disposal | Heavy metals (including mercury)<br>Persistent organic pollutants | • potential bioaccumulation in biota | | locally/provincially | | | |
| Air Emissions | Dust and associated contaminants | • bioaccumulation of heavy metals (incl. mercury) in biota | | locally/provincially | | | |
| | Vehicle emissions (green house gases) | • indirect effects (green house gases- climate change) | | | | | locally/provincially |
| **Tar Sands Exploitation** | | | Lower Athabasca River Drainage Basin | | | | |
| Point Source and Non-Point Source Contaminant Loading | Alteration of material fluxes to surface waters | • eutrophication | | locally | | | |
| | Saline water discharge | • water quality impairment | | locally | | | |
| | Endocrine disrupting substances | • reproductive effects in biota | | | | | locally |

**Table 1. (continued)**

| Issue | Specific concern (or stressors) | Type of effects on aquatic ecosystem health | Distribution in Alberta | Severity | | | |
|---|---|---|---|---|---|---|---|
| | | | | Low | Moderate | High | Unknown |
| Landscape Changes (physical alterations) | Habitat alteration | • habitat loss | | | | locally | |
| Water Use /Water Allocation | Change in flow regime<br>Surface and sub-surface withdrawals | • habitat loss through reduced surface and base flows | | | | locally | |
| Tailings/Sludge Disposal | Heavy metals (including mercury)<br>Persistent organic pollutants | • bioaccumulation in biota | | | locally | | |
| Air Emissions | Acid inputs | • pH reduction in surface waters<br>• contaminant deposition and bioaccumulation in biota | | | locally | | |
| **Forestry** | | | Peace-Athabasca Drainage Basins | | | | |
| Point Source and Non-Point Source Contaminant Loading | Alteration of material fluxes to surface waters | • nutrient cycling | | | locally | | |
| | Wood preservatives | • water quality impairment | | locally | | | |
| | Chemical weed control | • potential chronic and acute toxicity | | locally | | | |
| Landscape Changes (physical alterations) | Vegetation removal | • habitat loss | | | locally | | |
| Water Use /Water Allocation | Altered stream flows | • habitat loss through reduced surface and base flows | | | locally | | |
| Air Emissions | Dust and associated contaminants | • bioaccumulation of heavy metals in biota | | locally | | | |
| | Vehicle emissions (green house gases) | • indirect effects (green house gases- climate change) | | | | | locally |
| **WATER MANAGEMENT AND CONTROL STRUCTURES (DAMS, RESERVOIRS, DIKES, DIVERSIONS, WEIRS)** | | | Province-wide | | | | |
| Landscape Changes (physical alterations) | Loss of terrestrial and lotic aquatic habitat | • implications on local biodiversity and foodchains | | | | locally | |
| | Seasonal and diurnal changes in natural flows<br>Changes in ice jam formation<br>Changes in natural food cycles<br>Instream flow needs | • habitat loss/degradation | | | locally | | |
| | Changes in chemical and physical process<br>Temperature and DO regime alterations | • habitat loss/degradation | | | locally | | |
| | Retention of suspended matter (sediment) | • nutrient cycling | | | locally | | |
| | Trophic upsurge<br>Mercury cycling and bioavailability | • productivity dynamics<br>• bioaccumulation of heavy metals in biota | | | locally<br>locally | | |
| Water Use /Water Allocation | Interbasin transfer<br>Instream flow needs | • habitat loss/degradation<br>• exotic species introduction | | | | | Future/Emerging |

**Table 1. (continued)**

| Issue | Specific concern (or stressors) | Type of effects on aquatic ecosystem health | Distribution in Alberta | Severity | | | |
|---|---|---|---|---|---|---|---|
| | | | | Low | Moderate | High | Unknown |
| **INDUSTRIAL DEVELOPMENT** | | | | | | | |
| **Pulp Mills** | | | Athabasca | | | | |
| Point Source Contaminant Loading | Nutrients | • eutrophication | Peace-Athabasca Drainage Basins | | | | |
| | Endocrine disrupting substances | • reproductive effects in biota | | | locally | | |
| Water Use /Water Allocation | Instream flow needs | • habitat loss/degradation | | | | | locally |
| Biosolids/Sludge Disposal | Heavy metals (incl. mercury) | • potential bioaccumulation in biota | | locally | | | |
| | Persistent organic pollutants | | | locally | | | |
| Air Emissions | Dust and associated contaminants | • bioaccumulation of heavy metals in biota | | | | | |
| | Air emissions (green house gases) | • indirect effects (green house gases- climate change) | | provincially/locally | | | |
| **Power Plants** | | | Peace, North and South Saskatchewan Drainage Basins | | | | provincially/locally |
| Water Use /Water Allocation | Water storage for hydropower | • habitat loss/degradation | | | | | |
| | Instream flow needs | | | | locally | | |
| Air Emissions | Dust and associated contaminants | • bioaccumulation of heavy metals in biota | | | | | |
| | Air emissions (green house gases) | • indirect effects (green house gases- climate change) | | locally | | | |
| | Acid inputs | • pH reduction in surface waters | | | | | locally |
| | | • contaminant deposition and bioaccumulation in biota | | locally | | | |
| **Petrochemical Industry** | | | North and South Saskatchewan Drainage Basins | | | | |
| Point Source Contaminant Loading | Heavy metals (including mercury) | • bioaccumulation in biota | | locally | | | provincially |
| | Petroleum hydrocarbons | • water quality impairment | | locally/provincially | | | |
| | Endocrine disrupting substances | • reproductive effects in biota | | | | | locally/provincially |
| Water Use /Water Allocation | Instream flow needs | • habitat loss/degradation | | locally | | | provincially |
| Air Emissions | Dust and associated contaminants | • bioaccumulation of heavy metals in biota | | locally | | | provincially |
| | Air emissions (green house gases) | • indirect effects (green house gases- climate change) | | | | | locally/provincially |
| **Food Processing Industry** | | | South Saskatchewan Drainage Basins | | | | |
| Point Source Contaminant Loading | Nutrients | • eutrophication | | locally | | | |
| Water Use /Water Allocation | Instream flow needs | • habitat loss/degradation | | locally | | | |
| **AGRICULTURE** | | | White Zone of Prairies | | | | |
| Point Source and Non-Point Source Contaminant Loading | Nutrients<br>Confined feeding operations | • eutrophication<br>• cyanotoxins<br>• biodiversity | | | provincially | locally | |
| | Pesticides | • potential chronic and acute toxicity<br>• impacts on biodiversity and food chains<br>• reduces vegetation abundance, richness and diversity | Most prominent in South Saskatchewan Basin | | locally | | provincially |

**Table 1. (continued)**

| Issue | Specific concern (or stressors) | Type of effects on aquatic ecosystem health | Distribution in Alberta | Severity | | | |
|---|---|---|---|---|---|---|---|
| | | | | Low | Moderate | High | Unknown |
| Point Source and Non-Point Source Contaminant Loading | Pesticides | • fish mortality<br>• decrease in food availability for fish, invertebrates and waterfowl<br>• decreases nesting habitat | | | locally | | provincially |
| | Pathogens | • potential impacts on aquatic biota, but mostly increased need to treat water for human consumption | | provincially | | locally | |
| | Sediments (air and water borne) | • clogging of substrate of fish spawning grounds | | provincially | | locally during very dry or wet periods | |
| | | • reduced primary and secondary productivity | | | locally | | |
| | Endocrine disrupting compounds | • disruption of endocrine functions of aquatic biota | | | | | currently issue scoping in Alberta |
| Biosolids/Sludge Disposal | Over-application of manure | • see nutrients and pathogens | | | white zone | locally | |
| Landscape Changes (physical alterations) | Draining of wetlands | • reduction of habitat, water retention capability, altered surface groundwater interactions | | | locally/provincially | | |
| | Impacts on hydrologic cycle | • flash runoff, reduced retention of water | | | | | |
| | Degradation of riparian areas | • elimination or degradation of buffer zones leads destabilization of shorelines, increased flux of contaminants, temperature regime alterations | | | locally/provincially | | |
| Water Use /Water Allocation | Instream flow needs | • fish habitat loss | Primarily southern Alberta | provincially | locally | | |
| | Irrigation return water | • water quality impairment | | provincially | locally | | |
| Confined Feeding Operations | Nutrients | • eutrophication | | provincially | | locally | |
| | Contaminants | • water quality impairment | | provincially | | locally | |
| Air Emissions | Dust and associated contaminants | • bioaccumulation of heavy metals in biota | | | | | locally/provincially |
| | Air emissions (green house gases) | • indirect effects (green house gases- climate change) | | | | | locally/provincially |
| **POPULATION GROWTH (URBAN AND RURAL)** | | | **All major urban centres and suburbs** | | | | |
| Point Source and Non-Point Source Contaminant Loading | Nutrients | • eutrophication | | provincially | locally | | |
| | Pesticides | • potential chronic and acute toxicity | | provincially | locally | | |
| | Pathogens | • potential impacts on aquatic biota, but mostly increased need to treat water for human consumption | | provincially | locally | | |
| | Pharmaceuticals and personal care products | • endocrine disruption | | | | | locally/provincially |
| | Brominated flame retardants | • bioaccumulation in biota (organic contaminants) | | | | | locally/provincially |
| Landscape Changes (physical alterations) | Urban sprawl | • habitat loss (draining of wetlands) | | | provincially | locally | |
| Water Use /Water Allocation | Increased consumptive uses | • habitat loss/alteration | | | provincially | locally | |
| | Increased stormwater and runoff | • water quality impairment (see pathogens, nutrients) | | | locally/provincially | | |
| Landfills and Waste Disposal | Heavy metals | • potential bioaccumulation in biota | | provincially | locally | | |
| | Persistent organic pollutants | | | | | | |
| Air Emissions | Vehicle emissions (green house gases) | • indirect effects (green house gases- climate change) | | | | | locally/provincially |

**Table 1. (concluded)**

| Issue | Specific concern (or stressors) | Type of effects on aquatic ecosystem health | Distribution in Alberta | Severity | | | |
|---|---|---|---|---|---|---|---|
| | | | | Low | Moderate | High | Unknown |
| **RECREATION** | | | Province-wide | | | | |
| Recreational Use | Increased demand on fish resources | • overharvesting of fish | | | | locally | |
| | Wastewater effluent | • water quality impairment (see pathogens, nutrients) | | | locally | | |
| | Beach modification/pier construction | • habitat loss/alteration | | | locally | | |
| | Access management | • sedimentation via off-road vehicle use | | provincially | locally | | |
| Exotic Species Introduction | Non-native species | • competition with native species | | | locally | | |
| | Genetically modified organisms (GMOs) | | | | | | locally/provincially |
| **TRANSPORTATION INFRASTRUCTURE** | | | Province-wide | | | | |
| Point Source and Non-Point Source Contaminant Loading | Highway maintenance<br>Road salting and sanding | • increase in surface water salinity<br>• water quality impairment (organic pollutants, pesticides and sedimentation) | | locally/provincially | | | |
| Landscape Changes (physical alterations) | Road and highway construction | • habitat loss/alteration | | locally/provincially | | | |
| | Bridge and culvert installation | • reduced fish passage | | locally/provincially | | | |
| | Stream channelization | | | locally/provincially | | | |
| | Wetland loss | | | provincially | locally | | |
| **NATURAL DISTURBANCES** | | | Province-wide | | | | |
| Landscape Changes (physical alterations) | Flooding, drought, suppression of fires, wildfires | • habitat loss/alteration<br>• implications on local biodiversity and foodchains<br>• water quality impairment (pathogens, nutrients, sedimentation) | | | locally | | |
| **CLIMATE CHANGE** | | | Province-wide | | | | |
| Landscape Changes (physical alterations) | Alteration of temperature regimes<br>Alteration of precipitation/ evaporation cycle<br>Altered runoff regimes (and fluxes of material from land to water)<br>Lake levels<br>Reduced snowpack<br>Extent of permafrost<br>Extreme weather events<br>Contaminant transport to water (water vs wind erosion)<br>UV light and carbon cycle | • habitat loss/alteration<br>• water quality impairment<br>• reduced flows<br>• bioaccumulation in biota | | | | | provincially |

## 3.2 REVIEW OF ISSUES

### 3.2.1 Contaminant Loading

Municipal effluents are complex mixtures of human waste, suspended solids, debris and a variety of chemicals derived from residential, commercial and industrial sources (Environment Canada 2001). Municipal effluents comprise the largest source of effluent discharge to Canadian waters. Urban runoff transported by sewers, drainage channels and streams is ultimately discharged to receiving waters. Wet weather increases transport of contaminants to receiving waters via urban runoff, resulting in ecosystem effects on a more seasonal cycle. Infectious diseases may inhabit urban wetlands used to control runoff.

In Alberta, approximately 33% of the total land base is currently used for farming (Alberta Agriculture, Food and Rural Development 2005). Contaminants in livestock waste include nitrate, ammonia, coliform bacteria, phosphorus, endocrine disrupters and pharmaceuticals (Environment Canada 2001). Intensification of agricultural production has increased the risk of water contamination unless substances such as mineral fertilizers, pesticides and manure are adequately managed. There can be environmental and human health consequences from nutrient, pathogen, pharmaceuticals and endocrine disrupting substances added to surface and ground waters from agricultural practices. There is inadequate knowledge of biogeochemical and hydrological cycles to predict the effects of changes in agricultural practices on water resources. Further research is required to validate newer molecular detection tools, understand the ecology of pathogens in aquatic ecosystems, better predict disease outbreaks, and improve emergency responses. Scientifically credible practices, standards, and codes for agriculture together with appropriate enforcement mechanisms, should be established to ensure protection of ground and surface waters and aquatic biota.

The five-year Canada-Alberta Environmentally Sustainable Agriculture (CAESA) Water Quality Study was conducted to help determine the impact of primary agriculture on water quality in Alberta's agricultural areas by monitoring farmstead wells and dugouts, surface waters and irrigation canals. The study concluded that agricultural practices are contributing to the degradation of water quality. Degradation risk is highest in those areas where greater amounts of fertilizer and herbicides are used and with higher livestock densities (Buchanan 1998, CAESA 1998, Anderson *et al.* 1998a and 1998b, Cross 1997, Fitzgerald *et al.* 1997).

Fitzgerald *et al.* (1997) showed that 32% of the wells tested exceeded at least one health related contaminant such as fluoride, arsenic, zinc, selenium, manganese, lead or nitrate, and 93% exceeded at least one aesthetic or physical guideline such as taste, odor, color or staining. Most of these ground water contaminants are derived from natural geology of the area rather than human impacts. About 14% of well water samples had total coliform bacteria and 6% had fecal coliform bacteria detections, with the shallower wells (<30 m) having two times higher levels than deep wells (>30 m). Human or animal waste likely reached the well directly from poor well connections rather than indirectly through the aquifer. The dugout study showed that 92% of samples had detectable levels of coliform bacteria, while 20 to 71% contained fecal coliform

bacteria levels that exceeded the *Guidelines for Canadian Drinking Water Quality*. Low but detectable levels of herbicides were found in 3% of the wells tested, in comparison to 48% of the dugouts. Most of the well detections were likely due to careless practices with handling herbicides and most dugout contamination from field runoff.

Surface water and irrigation canal studies showed that the levels of nitrogen and phosphorus in streams, lakes, and irrigation canals often exceeded water quality guidelines for the protection of aquatic life (e.g., CAESA 1998). Fecal coliform bacteria from agricultural sources and/or wildlife often caused surface water sources to exceed the human and livestock drinking water quality guidelines (e.g., CAESA 1998). Herbicides in agricultural water bodies exceeded guidelines for human and livestock drinking water in less than 1% of the samples (CAESA 1998), although guidelines for the protection of aquatic life and in particular irrigation guidelines were exceeded more frequently. Two herbicides, MCPA and dicamba, exceeded the irrigation water guidelines in up to 33% of water samples tested.

Industrial impacts on water in Alberta include a variety of contaminants. Contaminant loading occurs from coal mining, oil and gas exploration, tar sands exploration, pulp and paper, power plants and food processing. Alberta Environment regulates a wide range of industrial facilities in the province under the *Environmental Protection and Enhancement Act* and the *Water Act* (Alberta Environment 2005b). This is most commonly done through conditions set out in environmental licenses, approvals or codes of practice. Alberta Environment's Compliance Inspection Program ensures that facilities meet the conditions of their licenses, approvals or registrations.

#### 3.2.1.1 Pathogens

Pathogens are an infectious group of microorganisms including protozoans, helminth worms, viruses, fungi, algae, cyanophytes and bacteria that enter the receiving waterbody from primary sources including sewage systems, animal husbandry operations and biosolids/sludge disposal (WLAP 2001). Most pathogens are species-specific parasites with a life cycle that may infect biota throughout various levels of the food chain. The cycle typically starts in simpler life forms and is transmitted up the food chain by consumption or parasitism, ultimately cycling back to the original pathogenic organism.

Pathogens are known to infect all trophic levels, but much of the available information focuses on pathogens that impact humans. Examples of common human pathogens and their effects are *Giardia sp.* (giardiasis), *Clostridium botulinum* (botulism), *Plasmodium sp.* (malaria) and *Escherichia coli* (urinary tract infections, neonatal meningitis and intestinal diseases such as gastroenteritis). Pathogens that have impacted freshwater aquatic organisms include red tide, which is known to infect shellfish which are then consumed by humans, botulism, which can occur in wetland areas and has resulted in substantial waterfowl mortalities, and unidentified viral and fungal pathogens devastating amphibian populations (Environment Canada 2001).

Pathogens are found in the fecal wastes of livestock and wildlife and can enter the aquatic system in runoff from livestock operations (Edge *et al.* 2003, Chambers *et al.* 2002). Diseases such as botulism caused by the pathogen *Clostridium botulinum* cause illness in humans and

have also been linked to mortalities in waterfowl (Edge *et al.* 2003). Pathogens have been attributed to fungal and viral infections, resulting in drops in the amphibian and fish populations of aquatic systems (Edge *et al.* 2003).

Pathogens have also been found to act synergistically with pesticides and nutrients. Limb deformities in frogs have been linked to the combined effects of a parasitic nematode and pesticide contamination, while nitrate and phosphate levels have been found to increase the instances of bacterial infection on the exoskeletons of aquatic macroinvertebrates (Kiesecker 2002, Lemly 2000). On an ecosystem level, pathogens have the ability to alter the biodiversity of the receiving waters (Edge *et al.* 2003).

#### 3.2.1.2 Organic Pollutants/Oxygen Depleting Substances

Organic pollutants and oxygen depleting substances derived from resource-based industries including forestry, pulp and paper, and oil and gas, present numerous environmental issues (Pierce *et al.* 1998). Organic wastes exert an oxygen demand on the system, by consuming available oxygen through biological and chemical oxidation. Variable levels of oxygen depletion in an ecosystem can result in effects ranging from tissue damage and behavioral stress to death in aerobic organisms. Oxygen depletion can affect all aerobic organisms within the ecosystem and the level of effect tends to be related to the organism's oxygen requirements. Based on the mechanism of effect, impacts are experienced at the level of the individual, but can be observed on a population level under severe circumstances. Organic pollutants have been linked declines in bird reproduction, and sport fish and mammal numbers over time and acute impacts including fish kills that can destroy the majority of the impacted area's population.

#### 3.2.1.3 Nutrients

Organic wastes derived from resource based industries like forestry and pulp and paper may deliver nutrient loads in the aquatic receiving environment. Nutrient loading of phosphorus and nitrogen can result in algal blooms, eutrophication and increased aquatic plant growth. The effects of nutrient loads on the aquatic system are observed at the individual and population levels. Ecosystem impacts include:

- Eutrophication resulting in oxygen depletion, which can be severe enough to cause fish kills (Environment Canada 2001);
- Algal blooms resulting from nutrient enrichment can include cyanogens (blue-green algae), that produce neuro-, dermo- and hepato-toxins, which when consumed, may cause toxic symptoms in organisms including livestock, humans and waterfowl (Alberta Agriculture, Food and Rural Development 2002);
- Eutrophication can also alter nutrient ratios, which may affect the species compositions of algal communities (DFO 2004, Ongley 1996), and result in losses of habitat and biodiversity (Environment Canada 2001);
- Nutrient loading may result in increased condition factor and weight in fish species and mortality in amphibians (Environment Canada 2003a).

Agricultural runoff entering aquatic systems can be exceptionally high in concentrations of nutrients, particularly nitrogen and phosphorus used as fertilizers on the crops. Increased nutrient levels in aquatic systems causes eutrophication and can have the immediate effect of increased growth of instream vegetation, weeds and algae (Bingham 2005, Chambers *et al.* 2003, Louis *et al.* 1996). Invasive weeds can out compete native vegetation, causing a reduction in the plant diversity of the system (Tennessee Department of Environment and Conservation 2002, Louis *et al.* 1996). Excessive nutrient loading can lead to severe algae blooms which can increase turbidity and block sunlight and the photosynthetic functions of other vegetation, leading to a drop in dissolved oxygen available for aquatic organisms (Bingham 2005, Pokorny and Hauser 2002, Louis *et al.* 1996). As the algae die off, oxygen is further depleted in the water, causing fish and invertebrates to suffocate (Chambers *et al.* 2003, Pokorny and Hauser 2002, Gregorich *et al.* 2000). Reduced oxygen, increased turbidity and alteration in vegetation abundance and diversity can alter habitat for invertebrates that feed on particular vegetation, while growing over spawning beds and crowding nesting sites for birds (Chambers *et al.* 2003).

Nutrient loading can also have toxic effects on fish, amphibians, invertebrates, birds and some vegetation. The blooms of cyanobacteria or bluegreen algae, release toxins which can harm vertebrate species, including humans (Lee and Jones-Lee 2004, Chambers *et al.* 2002). Reliable prediction of blue-green algal blooms is rare but is thought to be related to nutrient loads (Environment Canada 2001). Ammonia and forms of nitrogen can be toxic to fish, frogs and salamanders in high concentrations (Chambers *et al.* 2002, Clarke and Baldwin 2002). High levels of nitrate and phosphate have also been found to increase bacterial infections in invertebrates, causing mortality and shifts in the invertebrate community (Lemly 2000). As with pesticides, nutrient loading in streams has the ability to alter the entire ecosystem, greatly decreasing the overall biodiversity of the system (Chambers *et al.* 2003, Lemly 2000).

#### 3.2.1.4 Sediments

Sediment resulting from erosion is a common pollutant originating from forestry and mining operations, some agricultural activities and urban storm water. Sediment-related impacts on aquatic ecosystems are either physical or chemical in nature. Physical effects include increases in turbidity and essential habitat loss due to deposition. Effects are observed in flora and fauna alike, where reduced light penetration reduces photosynthesis of aquatic plants and algae, and presence of sediment can result in fish injury and reduced spawning habitat availability (Ongley 1996). At the ecosystem level, sedimentation may alter or cause imbalances in aquatic ecosystems with far reaching implications including reduced benthic habitats for algae, insects and fish as well as changing potential food web interactions (Environment Canada 2001, Alberta Agriculture, Food and Rural Development 2002). Chemical effects relate to the small particle size of sediment, which tends to increase binding sites for chemical pollutants (i.e., metals, PAHs and organochlorines). One of the results of this chemical binding is the inclusion of typically hydrophobic pollutants in the waterbody (Ongley 1996). As aquatic organisms are not usually exposed to these pollutants, the effects can be severe. The sediment-bound pollutants are usually introduced to the food chain in the benthic organisms and move through the system

when these organism are consumed by higher trophic level organisms resulting in more concentrated levels at the top of the food chain (bioaccumulation).

The introduction or input of soil into the aquatic environment from agricultural runoff, removal of streamside vegetation, unregulated livestock access and erosion can contribute to eutrophication of the aquatic system, causing significant damage to the plant and animal communities (Ortega-Mayagoitia *et al.* 2003). Sediment entering the water increases the turbidity of the water which reduces the photosynthetic functions of plants and phytoplankton resulting in a drop in productivity of submergent vegetation as well as a possible increase in growth of emergent vegetation (Ortega-Mayagoitia *et al.* 2003, Tennessee Department of Environment and Conservation 2002).

Sediment input in aquatic systems can have an even greater effect on fish, amphibians and invertebrates. Increased turbidity can reduce visibility in the water, making prey more vulnerable to predators and interfering with other sight-reliance activities (Chambers *et al.* 2002). Decreased dissolved oxygen is another result of increased turbidity as organic matter decomposes (Tennessee Department of Environment and Conservation 2002). Suspended sediments can also enter the gills of fish and invertebrates, causing respiratory distress and suffocation (Chambers *et al.* 2002, Nerbonne and Vondracek 2001). Sediment eventually settles onto the stream or wetland floor where it can smother eggs and reduce habitat and food resources for benthic invertebrates by coating sand, gravel or cobble surfaces. Changes in benthic habitat and food sources will result in a shift in benthic invertebrate populations to favour filter feeders, omnivores and burrowing taxa (Nerbonne and Vondracek 2001). Fish spawning habitat may also be reduced as sediment covers the wetland or stream floor. Other effects of sedimentation include changes in temperature patterns, transport of pesticides, nutrients, metals and other contaminants into the aquatic system, decreasing depths of pools or wetlands and changes in flow patterns (Tennessee Department of Environment and Conservation 2002).

The alterations to habitat caused by sedimentation in streams and wetlands can force fish, amphibian and waterfowl populations to seek more suitable habitat elsewhere, resulting in a significant drop in local biological diversity (Nerbonne and Vondracek 2001, Kranz and Kifferstein 1998).

#### 3.2.1.5 Toxicants

Toxicants from pulp and paper, forestry, mining and oil and gas operations that are most likely to impact water sources include pesticides, metals and petroleum hydrocarbons.

Pesticides are a group of compounds, including herbicides, insecticides and fungicides, used to control weeds, insects, fungi, nematodes and rodents. Aside from the obvious effect of killing or controlling the intended target of the pesticide, impacts on aquatic systems can result from off-target movement. Such impacts may include altered growth, reproduction or survival patterns of aquatic organisms and result in a loss of biodiversity and disruption of predator-prey interactions. The mechanisms of these impacts are diverse and include inhibition of photosynthesis, lipid synthesis, cell growth and division, or of specific enzymes such as

acethylcholinesterase, and cell membrane disruptors. Bioconcentration (the pollutant is concentrated in the tissue of the organism – typically fatty tissue) and bioaccumulation were serious concerns associated with the use of various organochlorine-based insecticides in the 1960's and 70's, but are less of a concern with recent use pesticides.

The effects on aquatic life attributed to pesticide use in agricultural practices have been widely studied. There are 550 pesticide active ingredients currently registered in Canada and further work is proposed re-evaluating 400 older pesticides (registered before 1995) (Environment Canada 2001). Pesticides applied to crops and rangelands enter the aquatic system through runoff and groundwater leaching with both acute and chronic effects on the aquatic vegetation and organisms (Louis *et al.* 1996). Large concentrations of insecticides entering aquatic systems can be lethal to fish, zooplankton and macroinvertebrates, while herbicides can not only remove much of the submerged plants and macrophytes, but can also be toxic to fish (Lee and Jones-Lee 2004, Maguire *et al.* 2002, Manosa *et al.* 2001, Louis *et al.* 1996).

A recent overview of pesticide data for a wide variety of surface water types in Alberta, further illustrates the influence of urban, industrial, and rural pesticide use on pesticide concentrations and detection frequency in surface waters (Anderson 2005). In 1998, 9.3 M kg of active ingredient was sold to control pest species. An overview of pesticide data since 1995, indicated that 44 pesticides were detected in surface waters, including 33 herbicides, 10 insecticides and 1 fungicide (Anderson 2005). Detection patterns are related to sales and use patterns across the province, but are also influenced by compound-specific characteristics. Agricultural and urban influences are shown in higher pesticide detection frequency, larger pesticide diversity and higher pesticide concentrations. Use patterns combined with climatic influences result in seasonal and long-term changes in the prevalence of pesticides. Overall, Canadian Water Quality Guidelines for irrigation, protection of aquatic life and drinking water were exceeded in 26.9%, 3.5% and less than 1% of the samples, respectively. Although this frequency is not high, there are uncertainties about how comprehensively pesticide risk in surface waters can be assessed using current guidelines. These uncertainties stem from the fact that several compounds detected in Alberta do not have guidelines; furthermore guidelines apply to single compounds, and many samples have multiple pesticide occurrences or multiple incidences of non-compliance. Because of these uncertainties, the possibility of local chronic effects on aquatic life cannot be excluded.

Pesticides that enter the aquatic system in very low concentrations can have chronic effects on the aquatic ecosystem (Chambers *et al.* 2002). Weight loss, reduced disease resistance, impaired motor skills, impaired reproductive success, altered growth rates, loss of attention, and inability to respond to extreme temperatures are some of the effects pesticides can have on fish, amphibians and invertebrates (Lee and Jones-Lee 2004, Ward *et al.* 2002, Chambers *et al.* 2002, Louis *et al.* 1996).

Reduced density and abundance of both emergent and submergent vegetation in streams causes a loss of instream cover and rearing habitat for fish and invertebrates, as well as a loss of nesting cover and nesting habitat for shorebirds and waterfowl (Ewing 1999, Louis *et al.* 1996, Newton 1995). Habitat loss also results from a decreased availability of food, both by

invertebrates that rely on vegetation for food, and by the fish and birds feeding on the invertebrate population (Ward *et al.* 2002, Ewing 1999, Newton 1995).

An overall ecosystem effect of pesticides is decreased biodiversity as herbivorous invertebrates are replaced by scavengers, quick colonizing aquatic plants move in and dominate, and fish and birds leave for more suitable habitat (Manosa *et al.* 2001, Louis *et al.* 1996, Newton 1995). Pesticides have been known to have synergistic effects, causing significantly greater toxicity when combined, while pesticide exposure combined with the presence of a particular pathogen has been found to cause deformities in frogs (Kiesecker 2002, Louis *et al.* 1996). Pesticides have also recently been linked to the toxic effects of endocrine disruption, wherein very low concentrations can affect the hormone functions of fish causing male fish to become female (Louis *et al.* 1996).

Metal contaminants are primarily associated with metal mining operations but can also be associated with other industries. Although trace levels of metals are required for numerous biological functions, excess levels can have deleterious effects including mutations and carcinogenesis on individual organisms when levels are elevated.

Petroleum hydrocarbons are primarily associated with oil and gas operations but can also be associated with other industries as a fuel source for the operation. Environmental effects associated with petroleum hydrocarbons are numerous; however one of the major toxicity mechanisms in aquatic organisms is interference with normal embryonic development.

To complicate the understanding of toxicant impacts on the environment, it is found that the interaction of numerous toxicants can act synergistically to exhibit unexpected effects at concentrations below toxicological threshold values. Examples of chronic and acute effects of toxicants on aquatic organisms and communities include:

- Pesticides have been linked to the decline and disappearance of amphibians (Environment Canada 2004a) and the death of organisms;
- Organochlorine pesticides can affect piscivorous birds of prey resulting in reduced eggshell thickness and potentially reducing productivity, while lower concentrations of organochlorine pesticides also appear in piscivorous mammals, however these levels represent a much lower threat to individual and population health (Environment Canada 1998a);
- Persistent chlorinated compounds and petroleum hydrocarbons tend to be detected in all trophic levels and result in physical effects including cancers, tumors and lesions;
- Mercury is most likely to affect piscivorous species, especially those that consume older/larger fish, as fish become an environmental mercury source through bioaccumulation (Environment Canada 1998a);
- Lead commonly moves through the food chain from a sink in the benthos into foraging waterfowl, moving up through their predators;
- Toxicants may result in reduced immune response, tissue, cellular and DNA damage and teratogenic deformities (Ongley 1996);

- Polychlorinated biphenyls (PCBs) tend to affect mustelids then piscivorous birds, and have been linked to severe reductions in mink reproductive success and the threatened or extinct status of otter (Environment Canada 1998a);
- Polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) originating from pulp and paper operations have been identified to cause acute lethality to resident biota (Environment Canada 2001);
- Endocrine disruption; and
- Loss of biodiversity and habitat reduction.

#### 3.2.1.6 Endocrine Disrupting Substances

Many pollutants such as pesticides, metals, petroleum hydrocarbons, industrial chemicals, and drugs are also categorized as endocrine disrupting substances (EDS). EDS can exert an array of effects on growth, development and reproduction in biota at extremely low concentrations and these effects can be expressed in future generations (Environment Canada 2001). Sources of EDS include forestry, pulp and paper, oil and gas, metal mining, municipal and agriculture. Numerous EDS including alkylphenols, tributylin, and selected pesticides have been included on Environment Canada's priority substance list. The impact of endocrine disrupting substances on aquatic ecosystems has received national and international attention in the recent past.

EDS in pesticides enter the aquatic system through agricultural runoff, and agricultural waste and treatment ponds with detrimental effects on the reproductive systems and thyroid functioning of fish, birds and possibly amphibians (Hurley *et al.* 2004, Servos 2003, Environment Canada 1999, Olsson *et al.* 1998). EDS mimic fish and bird hormones, interfering with the normal hormonal balance of these animals with damaging results (Servos 2003, Matthiessen 2000).

Some of the effects EDS can have on fish and birds are deformities, embryo mortalities, abnormal sexual development with males becoming female, unusual mating behavior, inhibited growth and abnormal development, and depressed thyroid and immune functions in fish-eating birds (Servos 2003, Chambers *et al.* 2002, Colborn and Thayer 2000, Environment Canada 1999, Environment Canada 2001, Olsson *et al.* 1998). To date, very little research has been conducted on the effects of endocrine disrupters on aquatic communities, including whether EDS's are causing an unbalanced ratio of females to males in fish populations (Servos 2003, Colborn and Thayer 2000).

Although it is likely that EDS impact organisms throughout the food chain, much of the experimental effort has been driven towards economically important animals. Examples of EDS-related effects on aquatic organisms include:

- The capacity to affect growth, reproduction and development of aquatic organisms throughout all levels of the food chain (Environment Canada 1999);
- Skewed sex ratios, abnormal behavior, decreased testosterone production (Munkittrick *et al.* 1991)

- Deformities and embryo mortality in fish, reduced immune response in fish, abnormal development in molluscs, depressed thyroid activity in fish-eating birds and feminization of fish in the presence of estrogen-like compounds (Environment Canada 2003b);
- EDS associated with pulp and paper mills in Canada have been tied to decreased gonad weight in fish; and
- Laboratory investigations have shown endocrine disruption in fish, amphibians and other biota through exposure to EDS (Health Canada 2003).

#### 3.2.1.7 Wood Preservatives

Antisapstain chemicals protect processed softwood lumber from discolouration due to growth of fungi and moulds. Common antisapstains and wood preservatives include didecyl dimethyl ammonium chloride (DDAC), 3-iodo-2-propynyl butyl carbamate (IPBC), creosote, pentachlorophenol (PCP) and chromated copper arsenate (CCA) (Environment Canada 1998b). Experimentation indicates that common antisapstain chemicals can have acute and chronic effects of fish. Some of the chronic stress indicators identified in fish species that were exposed to these chemicals included biological and physical tissue changes (increased plasma, lactate and cortisol levels) and reduced swimming speed and disease resistance (Environment Canada 1998c). Similarly, antisapstain chemicals affected invertebrates but the impacts were less predictable than those for vertebrates that were studied. Based on typical concentrations and toxicological effects observed in the environment, antisapstain chemicals represent a minor risk to aquatic organisms relative to the other effectors described in this section; however, the effects of antisapstain chemicals can be increased through a synergistic interaction with other contaminants (Environment Canada 1998d).

#### 3.2.1.8 Pharmaceuticals and Personal Care Products

Recently the concerns about environmental contaminants has widened to include pharmaceuticals and personal care products (PPCP). PPCP encompass a broad class of chemicals, ranging from over-the-counter and prescription drugs, to sunscreen and fragrances. Most household chemicals on the market, from pharmaceuticals and hormones to detergents and disinfectants have, in one form or another, found their way into aquatic environments. PPCP are not lipophilic, so they do not bioaccumulate in the environment (Daughton and Ternes 1999). These chemicals are constantly entering the environment, resulting in long-term exposure for the aquatic ecosystem and little is known about the toxicology of these compounds (Boston University School of Public Health 2002).

Most ingested drugs are excreted in varying amounts of metabolized and unmetabolized forms. Metabolism may result in chemicals that are either more or less biologically active than the form in which they were consumed (Boston University School of Public Health 2002). Sewage treatment facilities, depending on their technology and the chemical's structure, are not always effective in removing the active chemical from wastewater. As a result, pharmaceuticals find their way into the aquatic environment, where they directly affect organisms and can be incorporated

into food chains. With a growing population and an increased demand for medicine, the amount of PPCP finding their way into the environment has been steadily increasing.

Research on the fate of pharmaceuticals has shown varying levels of hormones, antibiotics, blood lipid regulators, non-steroidal anti-inflammatory drugs, betablockers, antiepileptics, anti-depressants, anti-tumor agents, retinoids, impotence drugs, fragrances, antiseptics, sunscreen agents, bioactive food supplements, antimicrobials, and natural and synthetic steroids in sewage and the aquatic environment (Daughton and Ternes 1999, Halling-Sorensen *et al.* 1998, Jorgensen 2000, Kummerer 2001, Stuer-Lauridsen *et al.* 2000, Zuccato *et al.* 2000). Although their concentrations are extremely low (ranging from hundreds of parts-per-billion to less than one part-per-trillion), the long-term impacts are unknown. The main areas of interest focus on PPCP role in endocrine disruption and antibiotic resistance. Many of these drugs have similar biological mechanisms, so while individually the levels are low, when they occur together, the biological effects may be significant. Recent studies on the effects of pharmaceutical mixtures in aquatic ecosystems have found adverse effects on plankton, plants and fish (e.g., Renner 2002, Science Daily 2002).

#### 3.2.1.9 Brominated Flame Retardants

Brominated flame retardants (BFR) have routinely been added to consumer products for several decades in a successful effort to reduce fire-related injury and property damage. Recently, concern for this emerging class of chemicals has risen because of the occurrence of several classes of BFR in the environment and in human biota. The widespread production and use of BFR, strong evidence of increasing contamination of the environment, wildlife and people, and limited knowledge of potential effects heighten the importance of identifying emerging issues associated with the use of BFR (Birnbaum and Staskal 2004).

BFR have been found in air samples from the Great Lakes and the Arctic, surface sediment from Lake Ontario, suspended sediment from Wapiti River in Alberta, and sludge from sewage-treatment plants in Ontario (Environment Canada 2003c). Hamers *et al.* (2005) found that BFR, as well as their oxidised metabolites can interfere *in vitro* with endocrine pathways.

#### 3.2.1.10 Biosolids/Sludge Disposal

Canada ranks among the highest producers of solid waste in the industrial world with effects of mining wastes projected to last decades to millennia (Environment Canada 2001). Sludge generated at municipal wastewater treatment plants are applied to lands and can impact the surface waters and groundwater (Environment Canada 2001). Nutrients, metals and volatile organics are often detected in aquifers several kilometers from landfill sources. Biosolids from sewage treatment plants are disposed of in landfills and spread on land and contain the same contaminants as animal wastes. Further research is needed on the mobility of new chemicals in landfills, the transport of contaminants across the groundwater-surface water interface and the long-term release of nutrients and metals from biosolids (Environment Canada 2001).

### 3.2.2 Landscape Changes/Habitat Alteration

Forestry, pulp and paper, mining and oil and gas operations have the potential to physically alter aquatic ecosystems. Physical alterations occur when water is required for a process and is removed from or returned to the system (i.e., point sources), changes in landscape alter the flux of materials from land to water (i.e., non-point source contributions) or when aquatic systems are drained or filled-in (i.e., actual change to the physical characteristics of aquatic ecosystems). When water is returned to the system, it may carry many of the contaminants described above as well as changing flow regimes, temperature profile and other physical parameters of the system (such as light penetration, shade, cover, UV penetration). Removal of water from the system can result in a variety of impacts including:

- Fish stranding and restricted passage;
- Habitat fragmentation, which represents the greatest threat to biodiversity in Canada by impacting at the species level as well as the processes that drive biodiversity (Quebec Biodiversity Website 1999);
- Loss of wetted area, ultimately resulting in a loss of specialized habitat areas for benthic organisms, aquatic vegetation and aquatic animals; and
- The infilling of a wetland drainage has been identified as a factor in the loss of one-third of Canada's nationally listed species at risk.

The loss or alteration of aquatic habitat is one of the most noticeable and direct impacts of agriculture and one of the greatest impacts on biodiversity. The removal of streamside vegetation can result in erosion of the banks, widening of the stream channel and reduced shade which increases water temperatures (Pogue and Schnell 2001, Gregorich *et al.* 2000). Sedimentation resulting from erosion and runoff from fields can cause fish kills as well as covering sensitive feeding and spawning habitat for fish and invertebrates (Chambers *et al.* 2002). Increases in water temperature due to reduced shade can have detrimental effects on fish metabolism (Gregorich *et al.* 2000).

Changes to instream vegetation can alter spawning and feeding habitat for fish, as well as nesting habitat for birds (Chambers *et al.* 2002, Lambeck 1997). Loss of suitable habitat can inhibit vegetation growth, resulting in reduced plant community abundance and diversity (Chambers *et al.* 2002). Habitat loss will also drive fish, amphibians, birds and the invertebrates to compete for smaller areas or leave the local environment, resulting in declining local populations of these animals (Fletcher and Koford 2003, Gregorich *et al.* 2000).

Amphibian declines are related to the fragmentation of wetland habitat by agriculture. Wetlands are necessary for amphibian reproduction, development and foraging (Environment Canada 2004a, Environment Canada 1998a). Hatching success in amphibians appears to be depressed by adjacent agricultural activity and amphibian distribution may also be impacted (Environment Canada 1998a).

Crop production and livestock activities both can impact nearby wetlands. Wetlands have historically been drained and cleared to make room for crop production resulting in complete habitat loss for birds, fish, invertebrates and aquatic vegetation (Chambers *et al.* 2002, Gibbs 2000). However, this practice has seen a marked decline in recent years. Livestock operations can also have significant impact on wetland conditions. Cattle grazing in or adjacent to wetlands can reduce or remove emergent vegetation affecting the plant species composition, richness and density in the wetland (Rice 2004). Cattle can also trample the shoreline vegetation, contributing to erosion and sedimentation concerns that can impact water quality and reduce habitat for fish, waterfowl and invertebrate communities (Rice 2004, Stavne 2004).

The magnitude and extent of dam construction and associated water diversion, exploitation of groundwater aquifers, stream channelization and interbasin water transfer cause hydrological alterations that are having global–scale environmental effects (Rosenberg *et al.* 2004). The impacts of large–scale hydrological alteration include: habitat fragmentation within dammed rivers (e.g., Dynesius and Nilsson 1994); downstream habitat effects caused by altered flows, such as loss and deterioration of floodplains, riparian zones, adjacent wetlands, river deltas and ocean estuaries; deterioration of irrigated terrestrial environments and associated surface waters (e.g., McCully 1996); and dewatering of rivers, leading to reduced water quality because of dilution problems for point and non–point sources of pollution (NRC 1992, Gillilan and Brown 1997). Other effects of dams include downstream cooling (summer) or warming (winter) for sometimes extensive river distances below the dam, as well as changes in dissolved oxygen levels which can be negative or positive (e.g., super-saturation and gas bubble disease and increases in winter dissolved oxygen levels). In turn temperature and dissolved oxygen changes influence the distribution, diversity and productivity of in-stream biota. Less conspicuous impacts of hydrological alterations include: genetic isolation as a result of habitat fragmentation (e.g., Pringle 1997); changes in ecosystem–level processes such as nutrient cycling and primary productivity (e.g., Pringle 1997, Rosenberg *et al.* 1997); impacts on biodiversity (e.g., Rosenberg *et al.* 1977, Master *et al.* 1998, Richter *et al.* 1998, Wilcove *et al.* 1998); methylmercury contamination of food webs (e.g., Verdon *et al.* 1991, Kelly *et al.* 1997, Rosenberg *et al.* 1997); and greenhouse gas emissions from reservoirs (e.g., Duchemin *et al.* 1995, Kelly *et al.* 1997, Rosenberg *et al.* 1997).

Smaller scale effects of hydrological and habitat alterations can also result from dikes, diversions, weirs, levees, flood control structures, dredging, channelization, erosion controls, lake and wetland stabilization, storm water outfall structures, beach modifications, marinas, docks and piers.

The alteration of natural stream flow regimes can cause ecological degradation, loss of biodiversity and ecosystem integrity (Poff *et al.* 1997). There are five components of the flow regime that regulate ecological processes in river ecosystems including magnitude, frequency, duration, timing and rate of change of hydrologic conditions (Poff *et al.* 1997). These components can be used to characterize the entire range of flows and specific hydrologic events such as floods or low flows.

### 3.2.3 Water Use/Water Allocation

Population growth and distribution have always been linked to the availability of freshwater and the sustainability of renewable water resources. Only 0.26% of the world water is readily available for humans and other organisms. The demand for water has grown significantly over the last 50 years, not only because of population growth (8% use), but also because of an increase in the uses for industrial production (23% use) and agriculture (69% use) (Population Reference Bureau 2005, UNEP 1999). The world's population is already using about 54% of all the accessible freshwater and by 2025 this percentage will increase to 70%.

Ninety percent of Canadians live in a narrow band along the extreme southern edge of the country, which puts high and competing demands on some local water supplies. In Canada, the consumption per capita is very high and the municipal water use strains the capacity of surface water and groundwater supplies (Natural Resources Canada 2004). The demand for water exerts a major pressure on water resources with significant implications for issues of quantity and quality of water resources (OECD 2005, Gregorich *et al.* 2000), through water use for transportation, water supply, flood control, agriculture and power generation.

While agricultural practices withdraw comparatively less water than manufacturing or thermal power generation processes, the actual consumption of water is much greater in agriculture, with less than 30% of water being returned to the aquatic system (Chambers *et al.* 2002). These demands are resulting in reduced water levels in streams and ponds and drainage of wetlands causing habitat loss for birds, fish, amphibians, invertebrates and aquatic vegetation as well as drops in overall biodiversity (Gregorich *et al.* 2000). With the pending implications of climate change expected to cause drought and further reduction in water availability, aquatic ecosystems could suffer considerably more habitat loss (Chambers *et al.* 2002).

Efforts to increase or expedite water supply for agriculture have resulted in channelization of streams, cleared riparian vegetation and drained wetlands (Gregorich *et al.* 2000). Channelization of streams can increase currents causing erosion, loss of pool and riffle habitat and possible downstream flooding, while cleared riparian vegetation and drained wetlands result in decreased opportunity for groundwater recharge (Pogue and Schnell 2001, Lindqvist and Falkenmark 2000, Gregorich *et al.* 2000). Lower water levels are less able to dilute contaminants entering the aquatic system through runoff, reducing water quality (Gregorich *et al.* 2000). An overall effect of water demands on the aquatic ecosystem is a reduced ability to support a diverse community (Gregorich *et al.* 2000).

Alberta's surface water resources are located in glaciers, lakes and man-made reservoirs or flow through the province's rivers and streams (Alberta Environment 2005c). Although Alberta has a good supply of surface water, some regions may experience water scarcity at times because of geography, the distribution of the population, the climate and natural variability in climatic cycles. Most of Alberta's surface water resources lie in northern Alberta, while most of the population and agricultural/industrial demand occurs in the south. Groundwater is present in practically every part of the Province, but aquifer depths, yields and potability vary widely.

Of all the water that is allocated in Alberta, 98% comes from surface water and 2% comes from groundwater (Alberta Environment 2005c). The largest potential uses for surface water are irrigation (46%), commercial cooling (27%) and municipal water supply (11%). The largest potential uses for groundwater are for enhanced oil recovery (injection) (26%), municipal water supply (26%) and agricultural use (non-irrigation) (17%). These allocations do not represent the actual usage since the users do not necessary consume their full allocation and they may have return flows.

### 3.2.4 Air Emissions and Acidification

Air quality deteriorates when substances from natural or anthropogenic (human) sources accumulate in the atmosphere (Alberta Environment 2005d). Natural sources that release substances to the atmosphere that can affect air quality include windblown dust contributing fine particulate matter (including nutrients), forest fires and burning of vegetation release carbon dioxide, carbon monoxide, nitrogen oxides, ammonia and particulate matter, and volcanic activity releases large quantities of carbon dioxide and sulphur dioxide (smaller amounts of hydrogen sulphide, carbon monoxide, hydrogen chloride, and hydrogen fluoride). Vegetation and microbial activity are other natural sources of substances that can affect air quality, known as biogenic emissions. Plants produce a wide variety of organic compounds many of which are used for growth and development but some are released to the atmosphere (such as hydrogen sulphide and a variety of volatile organic compounds including isoprene, toluene and beta-pinene). Soil microbial activity can release carbon dioxide, methane and nitrogen oxides to the atmosphere.

The accumulation of substances in the atmosphere that have been released from human activities are responsible for the deterioration of air quality in many areas in the world (Alberta Environment 2005d). There are stationary sources such as factories, power plants and smelters that emit sulphur dioxide, metals, carbon dioxide and other substances, small stationary sources such as dry cleaners and degreasing operations emit volatile organic compounds, and mobile sources such as cars, buses, planes, trucks and trains emit nitrogen oxides, carbon monoxide, volatile organic compounds and particulate matter. Pesticides applied to agricultural land volatilize to some degree, largely depending on the characteristics of specific compounds. Once in the atmosphere, these chemicals can be transported for some distance and be deposited on land and water with wet or dry precipitation.

The effects of air pollution on ecosystems are diverse. In humans, the severity of the effects depends on the pollutant, the concentration in the atmosphere, the length of exposure and the sensitivity of the receptor (Alberta Environment 2005d). Poor air quality principally affects the respiratory and cardiovascular systems of humans.

Vegetation can be affected when a substance in the air enters the plant or is deposited in the soil then absorbed by the roots and transported to the leaves (Alberta Environment 2005d). In some cases sensitive species will be replaced by more resistant species, thereby reducing the biodiversity of the ecosystem. It is also possible for certain substances to buildup in the tissue

of vegetation which then have the potential to adversely affect the health of wildlife and animals using the vegetation as a food source.

Substances in the air can also be deposited into waterbodies, which could reduce the water quality and affect the health of organisms in that waterbody (Alberta Environment 2005d). If any of the organisms have been adversely affected by air pollution, the biodiversity of the ecosystem may be changed.

Sulphur and nitrogen dioxide emissions can cause acid rain. Alberta Environment (1999) has developed a framework based on the application of critical and target loads for managing acidifying emissions and acid deposition in Alberta. The approach to integrated acid deposition management includes the measurement and estimation of emissions and deposition and an evaluation of effects of deposition on ecological receptors. The primary receptors of acid deposition are soil and aquatic systems, which can alter the pH of the system. Alberta Environment (1999) has classified lakes within the province according to their sensitivity to acid input, based on the alkalinity of the water. Most water bodies within the province are at low risk for acidification, however some of the shield lakes in Northern Alberta are sensitive.

### 3.2.5 Exotic Species Introduction

Exotic species of aquatic organisms can be accidentally or deliberately moved from waterbody to waterbody. Introduction of exotic species can reduce biodiversity and may result in competition that could exclude native species. These effects have been observed in the Canadian prairies due to exotic species that include aquatic plants, microbes, fish and molluscs (SRC 1999, Parks Canada 2003). Exotics may also prey on components of the existing food web or compete with indigenous species for resources such as food or space. When natural predators of the exotic species are absent, native species can often become threatened or eliminated. In a few cases, another threat introduced with the exotic species is a new disease that is brought to the system, which can destroy non-resistant native species. Hybridization during reproduction between exotic and native species can also have negative impacts (i.e., gene pool deterioration or homogenization) (Kohler and Courtenay Jr. n.d.). Undesirable species, parasites and diseases can upset the delicate balance of ecosystems and sport fisheries, as well as cause millions of dollars in damage (ASRD 2002).

### 3.2.6 Climate Change

Climate change is a wide-scale change in the average weather, over a long period of time and usually refers to significant shifts from one climate system to another. The world's climate has always and will continue to change. Concern is growing because average global temperatures are rising. This seems to be occurring because of an increase in greenhouse gases, which trap heat in the atmosphere (i.e., greenhouse effect). The main gases linked with the greenhouse effect are water vapour, carbon dioxide and methane. Most greenhouse gases occur naturally, but human activity adds at least six billion tonnes of carbon to the atmosphere each year, leading to the risk of global warming, climate change and impacts on our quality of life.

Climate and stream flow records in Alberta are generally less than 100 years in length which is a short time period relative to the age of the earth (Alberta Environment 2005e). It can be difficult using this data to characterize how things might compare to the past, whether significant trends can be detected, and if recently observed patterns are driven primarily by natural phenomena or perhaps by human activity. The presence of cycles ranging from roughly decadal (about 10-20 years) to scales of thousands of years can be interpreted from recent and paleogeologic records, but these cycles are complex and not well understood. The current debate over climate change can be better characterized as a focus on whether humans are contributing to an apparent warming trend that has been observed in some places, including Alberta (Alberta Environment 2005e). Alberta is taking action to deal with the risks of climate change.

Sauchyn and Skinner (2001) have historical drought reconstruction information that shows the cycles of drought in Alberta from the 1600's to the present by the Palmer Drought Severity Index (PDSI) (Figure 1). PDSI is calculated based on precipitation, temperature and local available water content of the soil. Four to five droughts have occurred each decade in southeast Alberta and southwest Saskatchewan.

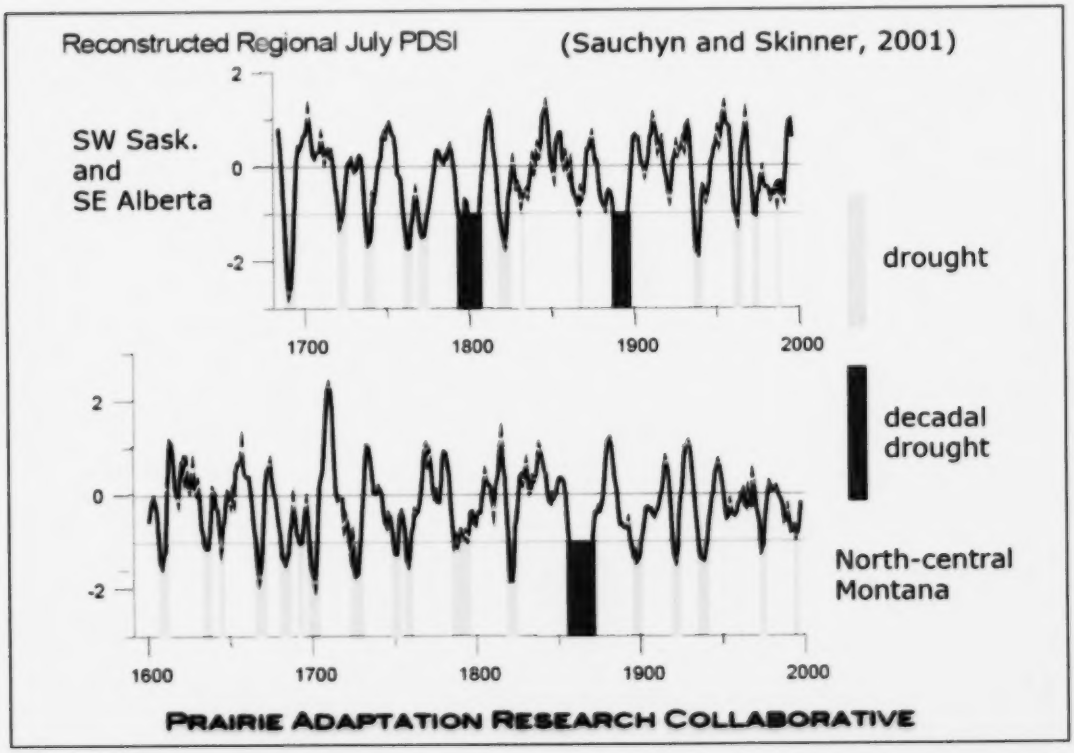


**Figure 1. Reconstructed regional PDSI for July for southwest Saskatchewan and southeast Alberta, and north-central Montana (Sauchyn and Skinner 2001).**

Analysis of historical stream flow data for Alberta indicates that it is not yet clear whether a long-term decline in stream flows may be occurring in Alberta (Alberta Environment 2005c). Both higher water diversions for consumptive uses, and potential effects due to climate change, can have the same net effect on water supply in that the amount of water available in lakes and rivers has been reduced. Drought can occur almost anywhere in the Province and can have relatively short-term but significant impacts on water supplies. In addition, allocations of water in some areas (particularly in the south) have nearly reached the limit of available supply, requiring more efficient use of the existing resource in order to support a growing population and economy.

In recent years, the occurrences of extreme events like ice storms, droughts and floods have been on the rise worldwide and some researchers have speculated that the prospect of an increase in hydrologic extremes is related to climate warming. There has been a warming trend in the Canadian Prairie provinces over the past 50 years, with the largest increases in the winter months (about 3°C) and the least over the summer months (about 0.2°C) (Partners for the Saskatchewan River Basin 2005). With the rise in temperature, snow fall precipitation has decreased, while spring snow melt is occurring earlier. Soil moisture conditions and the availability of water in rivers and reservoirs will depend on the combined effects of changes in precipitation and evaporation.

Climate change can be significantly affecting the ecology of Alberta. Some of the possible impacts include decrease in snow accumulation, increase in evapotranspiration, changes in warm air masses resulting in changes in precipitation, increased glacier melt, longer ice-free periods on lakes, increasing ground temperatures, decreasing water levels, shifts in the distribution of plants, birds and mammals to higher latitudes and altitudes, and earlier plant leafing and flowering (University of Alberta 2004, Alberta Environment 2005e).

Variations in climate can produce major changes in both water quantity and quality. Better understanding is required of the interactions between hydrological processes and biogeochemical responses, effects of changes in water quantity/quality on ecosystem structure and function, and interaction between changing hydrologic regimes and aquatic habitat quality. Knowledge is needed about water balances in altered landscapes and better methods are needed to predict how changes in the climate system affect the hydrologic cycle (Environment Canada 2001).

### 3.2.7 Recreational Use

Alberta's recreation and tourism industry is the fourth largest industry in the province, supporting a considerable number of recreational activities. The aquatic environment is a determining factor in the quality of the recreational activity, with poor water quality and dwindling stream flows impairing recreational use. Recreational activities are a relatively small user of water as compared to all the other uses – less than 1% of surface water and approximately 2% of all groundwater (WISE 2002). Water, snow and ice support a wide range of recreational and tourism related activities, all of which can have an impact on the health of Alberta's lake and stream ecosystems.

Alberta's water resources are used by over 60% of Alberta household's engaging in at least one water-based recreational activity including swimming, boating, fishing, sailing, canoeing, water skiing, windsurfing and rafting (Alberta Environment 1996). Lakes and southern Alberta's reservoirs are the most popular type of waterbody for these activities with numerous well-used camping facilities and privately owned properties. Of Alberta's sport fishing, 50% is conducted on lakes and reservoirs during the open-water season, 16% during winter ice cover, and 34% occurs on rivers and streams (Alberta Environment 1996). Alberta's lakes experience high fishing pressure. The lakes closest to urban centres receive the heaviest use and in some cases, these lakes have experienced reduced fishing success and a deterioration in water quality. Other recreational water-related activities include waterfowl hunting and "watchable wildlife" viewing, established near marshes and lakes. Harvesting living aquatic organisms including commercial fishing, domestic fishing and licensed trapping of semi-aquatic furbearers is another influence on aquatic ecosystems (Alberta Environment 1996).

### 3.2.8 Transportation Infrastructure

Transportation can contribute significantly to environmental effects in various ways ranging from atmospheric deposition of contaminants to the construction and maintenance of infrastructure such as roads and railways. Transportation can be an important source of air pollution for nitrogen, acid rain and particulates, with water being a good solvent for pollutants (Rodrigue 2003). Since atmospheric deposition can be a continuous accumulation and occur over a long period, it has a higher impact on lentic than lotic systems.

The use of road salt (sodium chloride - NaCl) as a deicer on roads is the preferred method to provide safe motor vehicle travel during winter months. It depresses the freezing point of water to melt ice. Road salt has the tendency to accumulate in snow and soils beside roadways. During the spring, the accumulated salt is dissolved by water and enters the groundwater and surface waters through runoff. High concentrations of salt, notably chlorine ions, in fresh water environments disrupt life cycles, contaminate the food chain and may be fatal to some organisms like larvae (Rodrigue 2003). Prolonged retention of salt in stream beds or lake beds decreases dissolved oxygen and can increase nutrient loading, which promotes eutrophication. In urban areas, infrastructure runoffs are collected by the sewage and storm water systems, which are then discharged to aquatic environments.

Transportation infrastructures including roads, railways and bridges can have important effects on aquatic ecosystems, particularly when developed over rivers or wetlands. The main effect of transportation infrastructure includes direct loss of habitat, degradation of habitat, habitat fragmentation and increased human exploitation of aquatic resources when roads are built in remote areas.

### 3.2.9 Natural Disturbances

Floods and droughts are neither random nor cyclic. The extremes of flood and drought occur within the context of climate, both local and global (Collier and Webb 2002). Floods are more localized than droughts, both in time and in space.

Drought is a persistent moisture deficiency below long-term average conditions over months or years, that on average, balance precipitation and evapotranspiration in a given area (Collier and Webb 2002). Moisture deficiency may have different consequences depending on the time of year, preexisting soil moisture content and other climatic factors such as temperature, wind and relative humidity. Hydrologic drought occurs when surface water supply diminishes during a dry period and if dry conditions continue, groundwater levels could drop. Agricultural drought occurs when a moisture shortage lasts long enough to negatively impact cultivated crops and ecologic drought is detrimental to native plants. Drought is expected to be the most significant effect of climate change on the Canadian Prairies. Drought will elevate the level of soil dusts in the atmosphere, increase fire hazards and cause loss of habitat in waterbodies.

Floods, whether widespread or local in scale, are set up by large-scale atmospheric processes. Flooding can occur suddenly out of a single summer thunderstorm, or can be caused by a months-long buildup of moisture, such as the fast melting of a heavy winter's accumulation of mountain snow or soil saturated by high seasonal rainfall (Collier and Webb 2002). Floods are shaped by the basin through which they flow and can cause major habitat alterations. Flooding can wash contaminants into surface waters such as livestock fecal matter or agricultural chemicals, or industrial and urban contaminants.

Forest fires are neither inherently good nor bad ecologically, but are simply a type of "disturbance" (Cilimburg and Short 2003). Forest fires can directly affect water quality in nearby waterbodies, particularly smaller, shallower waterbodies. In the short-term, fire consumes vegetation, downed woody debris and soil organic matter, it heats soil and waterbodies, and it kills animals unable to escape or avoid excessive heat and smoke (Cilimburg 2003). Fire can cause changes in the water chemistry, both as a by-product of heating and from smoke and ash inputs during the burning process. These changes include elevated water temperatures which can reduce the solubility of dissolved oxygen and increase the pH and nutrient levels. Immediate changes in water temperature and chemistry can kill fish, benthic invertebrates, amphibians and other animals. Enduring changes in the physical and chemical attributes of catchments and watercourses have longer-term effects on populations of aquatic biota. In general, fire effects depend largely on the pre-fire condition of these systems, the pattern and severity of forest fire, patterns of post-fire precipitation, and the nature and speed of post-fire vegetation changes in the affected forests. Fire-caused changes in soil productivity and forest structure direct future vegetation development, which, in turn, influences soil loss to erosion. Fire-caused changes in water temperature and sedimentation rates affect populations of aquatic organisms and fire-caused changes in forest development affect the abundances and distributions of other animals (Cilimburg and Short 2003).

## 3.3 ISSUES AFFECTING AQUATIC ECOSYSTEM HEALTH IN ALBERTA

An overview of the issues affecting aquatic ecosystem health in Alberta is provided in Table 2. Issues of concern in Alberta include the effects of natural resource exploitation, water management and control structures, industrial developments, agriculture, population growth, recreation, transportation infrastructure, natural disturbances and climate change. The issues

with the most number of potential effects from stressors, ranging from contaminants to habitat alteration, include natural resource exploitation, agriculture and population growth. These are followed by water management and control structures, industrial development, recreation and natural disturbances. The stressors with the highest severity, usually locally, are contaminant loading, habitat alteration and water use effects. Contaminant loading includes a variety of parameters with the highest severity of effects from nutrients, sediment and metals, and to a lesser extent from pathogens, organic pollutants, pesticides, salinity and contaminants from biosolids. Little is known about the severity and extent of effects from EDS, pharmaceuticals and BFR. Air emissions effects are low in severity resulting mainly from natural resource exploitation and industrial development. Exotic species introductions and overharvesting of biota are local effects resulting from recreation.

**Table 2. Overview of severity of issues, locally and/or provincially, affecting aquatic ecosystems in Alberta.**

| Issues | Specific Concerns or Stressors | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pathogen | Organic Pollutants | Nutrients | Sediment | Pesticides | Metals | EDS | Pharma-ceuticals | Salinity | BFR | Biosolids | Habitat Alteration | Water Use | Air Emissions | Exotic Species | Over-harvesting |
| **Natural Resource Exploitation** | | | | | | | | | | | | | | | | |
| Coal Mining | | | ○ | ● | | ◑ | | | | | | ● | ◑ | ○ | | |
| Oil and Gas | | ○ □ | ○ □ | | ○ □ | ○ □ | | | ○ □ | | ○ □ | ● ◨ | ○ □ | ○ □ | | |
| Tar Sands | | ◑ | ○ | | | ◑ | Ⓤ | | ○ | | | ● | ● | ◑ | | |
| Forestry | | | ◑ | | ○ | ○ | | | | | | ◑ | | ○ | | |
| **Water Management/Control Structures** | | | | | | | | | | | | | | | | |
| Dams, Reservoirs and Diversions | | | | ◑ | | ◑ | | | | | | ● | ◑ | | Ⓤ | |
| **Industrial Development** | | | | | | | | | | | | | | | | |
| Pulp Mills | | ○ | ◑ | | | ○ | Ⓤ | | | | ○ | ○ | ○ | ○ | | |
| Power Plants | | | | | | ○ | | | ○ | | | ◑ | ◑ | Ⓤ | | |
| Petrochemical | | Ⓤ | Ⓤ | | | ○ | Ⓤ | | ○ | | | ○ | ○ | Ⓤ | | |
| Food Processing | | | ○ | | | | | | | | ● | ○ | ○ | | | |
| **Agriculture** | ● □ | | ● ◨ | ● □ | ◑ | | Ⓤ | Ⓤ | ◑ | | ● ◨ | ◑ ◨ | ◑ □ | Ⓤ | | |
| **Population Growth (Urban and Rural)** | ◑ □ | ◑ □ | ◑ □ | | ◑ □ | ◑ □ | Ⓤ | Ⓤ | | Ⓤ | ● □ | ● ◨ | ● ◨ | Ⓤ | Ⓤ | Ⓤ |
| **Recreation** | ◑ | | ◑ | ◑ □ | | | | | | | | ◑ | | | ◑ | ● |
| **Transportation and Infrastructure** | | ○ | | ○ | Ⓤ | | | | ○ □ | | | ◑ □ | | | | |
| **Natural Disturbances** | ◑ | | ◑ | ◑ | | | | | | | | ◑ | | ○ | | |
| **Climate Change** | | | Ⓤ | Ⓤ | | | | | Ⓤ | | | Ⓤ | Ⓤ | | | |

○ Locally Low
◑ Locally Moderate
● Locally High
□ Provincially Low
◨ Provincially Moderate
■ Provincially High
Ⓤ Unknown
Blank No concerns.

EDS endocrine disrupting compounds
BFR brominated fire retardants

# 4.0 Review and Evaluation of Aquatic Monitoring Techniques

## 4.1 BACKGROUND

With regional, national and global processes affecting both the structure and function of lakes, rivers and wetlands, assessment methodology must encompass many attributes to evaluate the impact of these processes on water quality. Many of the changes in biological communities correlate to resource exploitation, non-point pollutant interactions and habitat alteration. This creates the need for ecologically-based approaches to the issues. Biological monitoring is a fundamental part of an ecologically-based approach and allows for the assessment of environmental health of the aquatic resources (Stanford 1994).

Aquatic monitoring consists of three fundamental approaches which provide valuable indications of the overall health of the ecosystem:

- chemical measurements (nutrients, metals, organics, etc.),
- physical measurements (temperature, flow, etc.), and
- biological measurements (abundance and variety of aquatic plant and animal life, biological processes such as growth and reproduction of selected species, photosynthesis, etc.).

Aquatic biomonitoring programs are generally designed to measure the response of natural aquatic communities to anthropogenic stresses. Historically, the monitoring programs have focussed on attributes of the chemical and physical water quality and sediment quality (Meredith *et al.* 2003), but there is a link between the potential health of the biota and the physical habitat. There are some methods that add a predictive capacity to the assessment of the physical condition of streams (Davis *et al.* 2000). Many organizations are shifting their emphasis to biota, community and ecosystem measurements as indicators of broader environmental condition rather than narrower water quality condition or compliance with guidelines or standards. Periphyton, zooplankton, macroinvertebrates and fish assemblages can be used to assess stream health, integrating the effects of past and present exposure to contaminants and pressures (Fang *et al.* 2004, Parsons *et al.* 2002, Barbour *et al.* 1999). However, biological monitoring does not replace chemical and physical monitoring, instead they all provide information that supplement each other.

The value in doing biological monitoring is that aquatic organisms act as natural monitors responding to their total environment. They respond to all types of disturbances and toxicants, which can be assessed from relatively infrequent sampling of the community. The biological information is used to evaluate waterbody impacts from point and non-point sources of pollution (Plotnikoff and Wiseman 2001). As an ultimate use of biological information, the United States Environmental Protection Agency conducts monitoring to determine if a waterbody is attaining its specified designated aquatic life use by comparing the assessment results with the biocriteria established for that waterbody.

Surface water quality assessments have been conducted on rivers and lakes in Alberta since the 1940s (Alberta Environment 2005f). More systematic data collection programs were implemented in the late 1960s, to assess problems caused by excessive nutrients and oxygen-demanding substances entering the aquatic environment from municipal and industrial sources. In the 1970s assessments expanded to include non-point source issues associated with logging, agriculture, mining, urban runoff and atmospheric deposition. As analytical methods evolved in the 1980s and 1990s, it became possible to measure increasingly small amounts of an increasing number of chemicals. Concerns about the general health of aquatic ecosystems was reflected in the presence of these minute quantities of toxic substances in water, sediments, plants and animals. The tendency for contaminants such as pesticides and other organic compounds to bioaccumulate was recognized as a concern for human heath (Alberta Environment 2005f). Recently the presence of pharmaceuticals (including hormones and antibiotics), pathogens (viruses, bacteria, protozoans) and new agricultural chemicals in aquatic ecosystems mainly from large urban areas and intensive agricultural operations have become a concern. Other recent issues include the determination of minimum in-stream flow requirements to protect water quality as a result of the possible decline in stream flows and water quantity in Alberta, lake management, and watershed based nutrient impacts (Alberta Environment 2005f).

## 4.2 REVIEW OF AQUATIC MONITORING PROGRAMS

### 4.2.1 Alberta

#### 4.2.1.1 Northern River Basins Study/Northern Rivers Ecosystem Initiative

The Northern River Basins Study (NRBS) was designed to address the ecological concerns of industrial, agricultural, municipal and other developments, and to increase scientific knowledge about conditions in the Peace, Athabasca and Slave rivers. The study, initiated in 1992, was jointly sponsored by the governments of Canada, Alberta and the Northwest Territories. The study's objectives were to gather and interpret sound scientific information about the basins, develop appropriate recommendations for basin management and communicate effectively with the public. The NRBS conducted research in the areas of contaminants, drinking water, food chain, hydrology/hydraulics, nutrients, other river uses, synthesis and modelling, and traditional knowledge with a final report and recommendations completed in 1996 (Alberta Environment 2002).

The NRBS determined that the ecosystem approach to environmental management is needed to recognize the complex interactions that occur within individual systems. Each system is fundamentally unique and will react to environmental stressors in a distinctive manner. The NRBS proposed that the perception of health will vary with each ecosystem and over time. This strategy proposes that the desired structure and function of the ecosystem being managed will arise through a process that combines the best available scientific knowledge with societal expectations and concerns.

The NRBS developed a framework for monitoring and assessing ecosystem health in order to decide what needs to be monitored and for what reason. It also provided a mechanism for

measuring the combined effect of multiple environmental stressors on an ecosystem (i.e., cumulative effects). The framework was designed to be a dynamic and an iterative process that can respond to changing societal priorities, new scientific information, evolving environmental regulations and other issues. There are five general steps in the framework.

1. Identify Ecosystem Goals - A group of stakeholders, armed with the best available scientific information, begin to describe what they want from the ecosystem. They define what constitutes "ecosystem health" with regard to their specific situation.
2. Develop Specific Management Objectives - Once the goals are defined, they must be further refined into a specific management strategy. This general action plan describes what information is required to address the situation. Knowledge of current monitoring and regulatory requirements may influence the strategy.
3. Select Appropriate Ecosystem Indicators - The management strategy leads into the choice of specific indicators - those aspects of the ecosystem that can be monitored to reveal its ongoing status. The indicators can be chemical, biological or sociological depending upon the situation.
4. Monitor and Assess the State of the Chosen Indicators - An effective monitoring program will assess the indicators and report back to the stakeholders on the state of ecosystem health.
5. Take Appropriate Action - Information generated through this process will be used to guide environmental planning and management decisions. It will also feed into new or refined ecosystem goals.

The Northern Rivers Ecosystem Initiative (NREI), a five-year follow-up program, was the Governments of Canada, Alberta and Northwest Territories response to the recommendations of the NRBS. Through NREI, science teams focused on priorities such as pollution prevention, long range transport of air pollutants, contaminants, nutrients and dissolved oxygen, endocrine disruption in fish, drinking water, and enhancing environmental effects monitoring. Studies also continued into the incidence of fish abnormalities and the effects of land use, flow regulation and climate change on aquatic ecosystems.

#### 4.2.1.2 Regional Aquatic Monitoring Program

Initiated in 1997, the Regional Aquatics Monitoring Program (RAMP) is a joint environmental monitoring program that assesses the health of rivers and lakes in the Oil Sands Region of northeastern Alberta (RAMP 2003). The program is designed to identify and address potential impacts of oil sands development and is frequently adjusted to reflect monitoring results, technological advances and community concerns.

The objectives of RAMP are to:

- monitor aquatic environments in the oil sands area to assess effects of all activities on the rivers and lakes,
- collect data and better understand the oil sands area,

- compare actual monitoring data with Environmental Impact Assessment predictions,
- ensure the right actions are taken if problems are found, and incorporate traditional knowledge into monitoring activities.

The program includes environmental monitoring for water quality and sediment in rivers, fish in rivers, benthic invertebrates in rivers and lakes, water quality in wetlands and acid-sensitive lakes, and hydrology and climate measurements.

#### 4.2.1.3 Alberta Biodiversity Monitoring Program

The Alberta Biodiversity Monitoring Program (ABMP) is a partnership among Alberta industry, government, research institutes and academia for the purpose of monitoring long-term, broad-scale changes in biodiversity (ABMP 2005). By having a consistent long-term biodiversity monitoring program that is implemented throughout the province, it is possible to effectively and efficiently amalgamate biodiversity information across political boundaries and to evaluate whether biodiversity in a region is being affected by human activity. Development of the biodiversity monitoring program is occurring in three phases: technical design (1998 – 2002), testing and refinement (2002 – 2006) and implementation (starting in 2007). An integrated set of protocols for sampling a wide range of species and habitat characteristics was developed in Phase 1 for terrestrial upland, standing water, and stream environments. Field protocols were organized into 6 suites for efficient implementation, supplemented by multi-scale remote sensing protocols to detect habitat changes at the landscape scale.

The ABMP will include the development of a list of aquatic and terrestrial attributes to be sampled at specified locations within Alberta having a wide range of land use histories including those with limited human influence, the development of a plan for the periodic sampling of these attributes including spatial arrangement of sample locations, sampling frequency and field sampling methodologies, the development of a plan for the periodic reporting of landscape composition and pattern within Alberta using remote sensing technology, the estimate of natural variability to assist in interpretations of the significance of any changes observed (i.e., statistical power to detect change in monitored attributes), and an analysis of program effectiveness. Aquatic biotic elements to be monitored will include phytoplankton, zooplankton, benthic algae, benthic macroinvertebrates and fish, while habitat elements will include water physiochemistry, stream channel and basin attributes. Monitoring sites will be placed on a systematic grid to maximize the long-term value of data collected by the program. Each site will be re-surveyed every five years, with 10% of the sites monitored in consecutive years to allow statistical connectivity between years.

#### 4.2.1.4 South Saskatchewan River Basin Water Management Plan

Alberta Environment is developing a water management plan to maximize the benefits of water use in the South Saskatchewan River Basin (SSRB) in a sustainable and environmentally responsible way (Alberta Environment 2003, Alberta Environment 2004). The SSRB includes the sub-basins of the Red Deer River, Bow River and the Oldman River, including the South

Saskatchewan River. The planning process is a combined effort of Alberta Environment, Alberta Agriculture, Food and Rural Development, Alberta Sustainable Resources and Fisheries and Oceans. Phase one of the water management plan was approved in June 2002 and authorizes water allocation transfers within the SSRB, subject to Alberta Environment approval and conditions. Phase two will address water management issues, including the availability of water for future allocations and river flows for the aquatic environment (Alberta Environment 2003). Phase two seeks to find the best balance between water consumption and environmental protection in the SSRB. This includes defining water conservation objectives (i.e. the flow to remain in rivers) after consideration of economic and social values and ecological requirements. Studies either completed or underway identify the status of water allocations, current status of the aquatic environment and river flows required for protecting the aquatic environment, estimates of future human demands for water, and sub-basin flow contributions.

### 4.2.2 Canada

#### 4.2.2.1 Environmental Effects Monitoring

Environmental Effects Monitoring (EEM) is a science-based tool that can detect and measure changes in aquatic ecosystems (i.e., receiving environments) potentially affected by human activity (i.e., effluent discharges) (Environment Canada 2005). EEM is an iterative system of monitoring and interpretation phases that can be used to assess the effectiveness of environmental management measures and the sustainability of human activities on ecosystem health.

EEM is currently a requirement for regulated mills and mines under the *Regulations Amending the Pulp and Paper Effluent Regulations* (RAPPER) and the *Metal Mining Effluent Regulations* (MMER), both under the authority of the *Fisheries Act* (Environment Canada 2005). The objective of the EEM programs is to evaluate the effects of effluents on fish, fish habitat and the use of fisheries resources by humans. The information generated by the EEM program will be used to help assess the adequacy of the regulations to effectively protect these aquatic resources. As such, EEM goes beyond end-of-pipe measurement of chemicals in effluent to examine the effectiveness of environmental protection measures directly in aquatic ecosystems.

EEM consists of biological, water quality and effluent monitoring. Effects on fish are assessed through comparison of adult fish exposed to effluent with unexposed fish and effects on fish habitat are assessed through comparison of benthic invertebrate communities from areas exposed and not exposed to effluent. Effects on the use of fisheries resources are assessed by comparing designated contaminants (i.e., dioxins and furans for pulp and paper, mercury for metal mines) in fish tissue against fish health consumption guidelines, as well as tainting studies. In addition, effluent quality is monitored through sub-lethal toxicity testing, and effluent characterization and water quality monitoring studies are also required for metal mines.

The EEM program is designed to determine whether effects have been caused by the pulp and paper or metal mine discharges. An effect is defined as a statistically significant difference in benthic invertebrate community variables (richness, abundance, Simpson's Evenness Index and the Bray-Curtis Index) and fish variables (gonad size, live size and growth) measured between

an exposure area and a reference area (Environment Canada 2000). An effect for benthic invertebrate variables is defined as ± 2 standard deviations of the reference mean and differences of 25% or more in fish endpoints.

#### 4.2.2.2 Municipal Wastewater Effluent Monitoring

At present, Municipal Wastewater Effluent (MWWE) is one of the largest sources of pollution, by volume, being discharged to surface water bodies in Canada (CCME 2005). MWWE is defined as wastewater discharged to surface water from a municipal/community collection or treatment system, including end-of- pipe discharges and overflows but not separate storm water discharges. Reducing the discharge of pollution through MWWE requires a number of interventions ranging from source control to end-of-pipe measures. MWWE is currently managed through a variety of policies, by-laws and legislation at the federal, provincial/territorial and municipal levels. The Canadian Council of Ministers of the Environment (CCME) has formed a Development Committee (DC) to develop a national strategy for the management of MMWE by November 2006.

The majority of jurisdictions in Canada and internationally presently emphasize a technology-based approach for managing MWWE, with some jurisdictions (e.g., United States, Alberta) also using environmental risk-based approaches to establish more stringent limits or set effluent limits for non-conventional parameters (Minnow 2005). Although the specifics of the approaches differ, this is analogous to the EEM requirements in the Canadian *Fisheries Act* regulations respecting metal mines and pulp and paper mills.

Each of the various technology-based and environmental risk-based approaches are associated with advantages and disadvantages. The technology-based approaches employed in Canada generally accept varying degrees of treatment, with limits established based on the level of performance that can be expected from such treatment technologies. In contrast, the United States has established secondary treatment as the minimum acceptable standard, reflecting a value judgement that it is unacceptable to pollute when there is adequate technology to reduce pollutant loadings. The main advantage to an environmental risk-based approach is that MWWE treatment is geared specifically toward site-specific conditions and costs are thus proportionally allocated to sites that will likely demonstrate the greatest measurable improvement. With respect to environmental risk-based approaches, there are three general approaches that have been adopted among the various jurisdictions surveyed, each with its own benefits and limitations:

1. Derivation of site-specific effluent limits based on back calculation from water quality criteria developed to protect specific beneficial uses of the receiver (e.g., protection of aquatic life, recreation, drinking water, etc.).
2. Derivation of site-specific effluent limits based on protection against whole effluent toxicity (i.e., toxicity must not occur at concentrations exceeding the available dilution).
3. Surveys of receiving water biota to assess the efficacy of the established MWWE limits in terms of protecting such biota.

Any or all of these approaches will be considered as part of a potential framework for regulating MWWE in Canada. The strategy will also take into account the implementation and on-going operational costs to Canadian municipalities by allowing for flexibility in phasing in the approach.

#### 4.2.2.3 Ecological Monitoring and Assessment Network

The Ecological Monitoring and Assessment Network (EMAN) is made up of linked organizations and individuals involved in ecological monitoring in Canada to better detect, describe and report on ecosystem changes (EMAN 2003). The network is a cooperative partnership of federal, provincial and municipal governments, academic institutions, aboriginal communities and organizations, industry, environmental non-government organizations, volunteer community groups, elementary and secondary schools and other groups/individuals involved in ecological monitoring. EMAN was established in 1994 as a national network to provide an understanding and explanation of observed changes in ecosystems. The objectives of EMAN are to provide a national perspective on how Canadian ecosystem are being affected by multitude of stresses on the environment, provide scientifically defensible rationales for pollution control and resource management policies, evaluate and report to Canadians on the effectiveness of resources management policies, and identify new environmental issues at the earliest possible stage.

Surveys of recent ecological literature show that the overwhelming majority of studies are based on two species in less than two square metres and for less than three years. This does not provide for a regional, provincial or national picture of the status of, or processes within Canada's environment. EMAN can provide cross-disciplinary and cross-jurisdictional assessments of ecosystem status, trends and processes based on the coordination of data interpretation and communication among its partners and sites.

EMAN recommends that the groups who are involved in monitoring activities should coordinate their efforts through the use of standard protocols in study design, sampling procedures, sample and data analysis and reporting methods. The EMAN developed freshwater biodiversity monitoring protocols are organized into modules, which contain a distinct collection of protocols based on biological groupings. These protocols include sampling and data analysis procedures for lentic and lotic benthic macroinvertebrates, parasites from host fish populations, phytoplankton, zooplankton and ice phenology.

#### 4.2.2.4 Canadian Aquatic Biomonitoring Network

Canadian Aquatic Biomonitoring Network (CABIN) is a collaborative programme developed and maintained by Environment Canada to establish a network of reference sites available to all users interested in assessing the biological health of fresh water in Canada (Environment Canada 2004b, Reynoldson *et al.* n.d.). The purpose of environmental assessment and management is ultimately the maintenance of biological integrity. Bioassessment methods use living organisms to provide insight into environmental conditions. Several different biotic groups have been used in bioassessment, but one of the most useful groups are the benthic (bottom-dwelling) invertebrates. Benthic invertebrates are ideal for use in bioassessments because they are sedentary, and thus constantly exposed to the effects of pollution, they are reasonably long-

lived (1-3 years in north-temperate waters) so the effects of environmental stressors can be time-integrated, and they occur in high diversity, so many different species can potentially react to many different types of impacts.

The key to assessing the condition of our waterways through CABIN is the use of the Reference Condition Approach (Environment Canada 2004b). Reference sites are established based on minimal impacts by human use, and present users with a baseline for assessing potentially impaired sites. The reference sites represent as many different geographic regions and stream sizes as possible and are used to establish the type of community of organisms expected to occur in the range of natural habitat types present in regions covered by the CABIN network. Once the reference condition has been established, sites suspected of being impaired are sampled. Differences between the organisms found at the reference sites and the test-site indicate the extent, if any, of impairment at the site.

To support CABIN, Environment Canada will develop and maintain a database that will be web accessible, provide the necessary software for analysis of the condition of individual sites, provide annual training to participants in stream sampling and appropriate field protocols, provide training and certification in the identification of stream organisms, and provide quality assurance and control of both the data and identifications (Environment Canada 2004b). Participants in the CABIN Network will agree to use a standard set of field protocols, agree to provide their data to the network, maintain reference collections of organisms, and submit samples and participate in the quality assurance and control program.

#### 4.2.2.5 Canadian Community Monitoring Network

The Canadian Community Monitoring Network (CCMN) is a partnership between the Canadian Nature Federation (CNF), EMAN and a growing network of communities, organizations, individuals and government playing a role in community based monitoring (EMAN 2003). The CCMN is an initiative to enable communities to define and manage local sustainability through effective community based monitoring practices. By monitoring changes in the local ecosystem, partners of the CCMN can ensure that local policies and development trends are compatible with environmental values of the community. The network compiles and develops easy to use, inexpensive and scientifically valid protocols for monitoring environmental trends in a community.

### 4.2.3 United States

#### 4.2.3.1 Environmental Monitoring and Assessment Program

The Environmental Monitoring and Assessment Program (EMAP) is a United States Environmental Protection Agency (USEPA) research program to develop the tools necessary to monitor and assess the status and trends of national ecological resources (USEPA 2005a). EMAP's goal is to develop the scientific understanding for translating environmental monitoring data from multiple spatial and temporal scales into assessments of current ecological condition and forecasts of future risks to our natural resources.

EMAP aims to advance the science of ecological monitoring and ecological risk assessment, guide national monitoring with improved scientific understanding of ecosystem integrity and dynamics, and demonstrate multi-agency monitoring through large regional projects. EMAP develops indicators to monitor the condition of ecological resources, and investigates designs that address the acquisition, aggregation and analysis of multi-scale and multi-tier data.

#### 4.2.3.2 Rapid Bioassessment Protocols

The USEPA Rapid Bioassessment Protocols (RBP) are a synthesis of existing methods that have been employed by various State Water Resource Agencies (e.g., Ohio, Florida, Delaware, Massachusetts, Kentucky, Montana) (Barbour *et al.* 1999). The RBP advocate an integrated assessment, comparing habitat (physical structure, flow regime), water quality and biological measures with empirically defined reference conditions (through actual reference sites, historical data and/or modeling or extrapolation). The RBP focus on the evaluation of water quality (physicochemical constituents), habitat parameters, and analysis of the periphyton, benthic macroinvertebrate and fish assemblages.

#### 4.2.3.3 Bioassessment and Biocriteria Program

The USEPA Bioassessment and Biocriteria Program recommends that biological assessments and criteria can be an important component of State and Tribal watershed management programs (USEPA 2005b). Biological assessments are an evaluation of the biological condition of a waterbody using biosurvey data and other direct measurements of resident biota in surface waters. The presence, condition and numbers of types of fish, invertebrates, amphibians, algae and aquatic vegetation are data that together provide direct, accurate information about the health of specific waterbodies.

Biological criteria are narrative or numeric expressions that describe the reference biological integrity (structure and function) of aquatic communities inhabiting waters of a given designated aquatic life use. Biocriteria are derived from biological assessments involving integrated measures (indices) of the composition, diversity and functional organization of a reference aquatic community. The reference condition should represent unimpaired or minimally impaired conditions and the "high end" of the state's designated aquatic life use classification system (e.g., Ohio's warmwater habitat). Biological assessments are then conducted to determine if a waterbody is attaining its specified designated aquatic life use by comparing the assessment results with the biocriteria established for that waterbody. Stressors such as poor habitat quality, altered stream flows, high turbidity and sedimentation, low dissolved oxygen concentrations, eutrophication and contaminated sediments are proving more important than typically regulated pollutants in limiting the attainment of designated aquatic life uses (USEPA 2005b).

### 4.2.4 Australia

The Australia-wide Assessment of River Health (AusRivAS) utilizes a rapid standardized method for assessing the ecological health of rivers, based on biological monitoring and habitat assessment (Coysh *et al.* 2000, Department of Environment and Heritage 2005). The

AusRivAS monitoring program uses aquatic macroinvertebrates, which are a part of every inland aquatic ecosystem to assess the health of aquatic ecosystems. The program consists of a series of state-specific mathematical models which use field data to predict the aquatic macroinvertebrate families that would be expected to be present in surveyed river sites in a "reference" (pristine or near pristine) condition.

River health assessment is based on the differences between what is found at test sites and what was predicted to have occurred there from a set of reference sites with similar geographic, physical and chemical features. A ratio of the observed number of macroinvertebrate families to the expected number of families (the O:E score) can be calculated for each test site with a range of zero (impoverished - no families found at the site) to slightly greater than one (richer than reference condition - more than the expected number of families at the site). The O:E score provides a reliable, integrated river health indicator that is responsive to a variety of impacts, including water quality, habitat condition and changes in flow regime. This allows the general health of the river at the survey sites to be characterized and placed in a nation-wide context, but does not provide a definitive indication of the cause of a disturbance. Thus stressed or priority rivers can be identified for further investigation and management action.

### 4.2.5 South Africa

South Africa's new water law recognizes that protecting the needs of the environment requires tools that can be used to monitor environmental conditions as well as for setting ecological objectives to ensure the proper and sustainable management of the resource. The South African River Health Programme (RHP) incorporates several components of the biota, including macroinvertebrates, fish and riparian vegetation (Dallas 2000). The macroinvertebrate component utilizes the rapid bioassessment (RBA) technique, South African Scoring System, Version 4 (SASS4). It is a scoring system (1 to 15) based on riverine macroinvertebrates, whereby each taxon is allocated a sensitivity/tolerance score according to the water quality conditions it is known to tolerate. The higher the score the greater the organism's sensitivity and the lower its tolerance. Interpretation of SASS scores is based on two calculated values, SASS4 Score (the sum of the taxon scores for taxa present at a site) and Average Score Per Taxon (SASS4 Score divided by number of taxa). A monitoring site is considered impacted if the SASS Scores are lower than those expected at a site which is "minimally-disturbed" or "least- impacted" (reference site). The method was not designed to enable the exact nature of the disturbance to be determined, and it was intended that once an impairment of water quality had been established, it would be further assessed via intensive chemical and other studies.

To facilitate data interpretation and factor in regional biotic differences, a regional reference condition approach has been adopted in South Africa. In this way, data from a monitoring site is compared to an established reference condition or benchmark from a "least-impacted" site or sites. An ecological reference condition is the condition that is representative of a group of "least impacted" sites organized by selected physical, chemical and biological characteristics. Reference conditions, therefore, enable the degree of degradation or deviation from natural conditions to be ascertained and serve as a foundation for developing biological criteria for the

protection of aquatic ecosystems. A protocol has been developed for use in South Africa which adopts the regional reference condition approach but which also incorporates separate analyses of invertebrate communities which attempt to verify the spatial framework and to factor in potential variability resulting from physical, seasonal and habitat/biotope factors.

## 4.3 REVIEW OF AQUATIC MONITORING COMPONENTS

Table 3 provides a summary of the various components, which can be used for aquatic ecosystem health monitoring.

### 4.3.1 Physical Habitat

The condition or health of a waterbody may be influenced by a number of factors, including its ecological status, water quality, hydrology, geomorphology and physical habitat (Maddock 1999). Physical habitat is the living space of aquatic biota determined by the interaction of the structural features of the waterbody (within the waterbody and the surrounding topographical features including riparian areas) and the hydrological regime (Maddock 1999). Physical habitat is a useful element to evaluate waterbody health since it provides the natural link between the physical environment and its inhabitants. Riparian areas, which provide a buffer and filter between the waterbody and the land, are important for forage, shelter, habitat and water quality for fish and wildlife (Cows and Fish 2005c). For riparian areas to be healthy, they need to function properly including trapping sediments, recharging ground water, providing primary productivity and supporting diversity.

An evaluation of habitat quality is critical to any assessment of ecological integrity (Raven *et al.* 1998). The presence of an altered habitat structure is considered one of the major stressors of aquatic systems (Karr *et al.* 1986). The presence of a degraded habitat can influence the structure and function of the aquatic community and sometimes obscure investigations on the effects of toxicity and/or pollution (Barbour *et al.* 1999).

A number of approaches have been developed that incorporate an element of physical habitat assessment (Maddock 1999), particularly for streams, although physical habitat features can also be assessed in lakes and wetlands. Some assess only the physical habitat and others assess the geomorphology or biota present within the waterbody and incorporate an element of physical habitat as part of the assessment. Different habitat assessment methods operate at different spatial levels (Maddock 1999). In streams, for example, the reach level assesses the overall features of the region, its topography and geomorphic or land use patterns. Dominant substrate, channel gradient, landform features, sinuosity, width and depth, and hydrological regime are measured to determine discrete reaches. The macrohabitat level assesses the habitat features of different sections of the stream such as average flow velocity, morphological type (riffles, pools), bank stability and riparian cover. The microhabitat level assesses the distribution of hydraulic and structural features of the living space of the organism, such as depth, velocity and substrate. One type of microhabitat assessment involves the Instream Flow Needs (IFN) methodology. It is based on the planning concepts of water supply, analytical models from

**Table 3. Summary of the various components, which can be used for aquatic ecosystem health monitoring.**

| Component | Description | Parameters Assessed | Evaluation | Indicator Type |
|---|---|---|---|---|
| Physical Habitat | Represents the structural environment in which aquatic biological communities live as well as the terrestrial environment, which has a direct influence on aquatic processes. Physical habitat comprises:<br>1. Hydrology<br>2. Channel Processes<br>3. Riparian zones<br>4. Watershed features | 1. Hydrologic or flow regime, allocation, Instream Flow Needs assessment.<br>2. Channel gradient, sinuosity, morphological types, substrate, flow velocity, depth.<br>3. Vegetative cover, invasive species, stream bank stability, human caused bare ground.<br>4. Soils and landscapes, vegetation, climate, human uses and impacts. | Physical habitat indicators are an essential component to the assessment of ecosystem health.<br>Physical habitat determines the structure and function of the aquatic community.<br>Physical habitat can obscure or mitigate effects of toxicity and/or pollution.<br>Physical habitat influences the fluxes of materials and energy from terrestrial to aquatic ecosystems. | Diagnostic |
| Water Quality | Aquatic communities are influenced by physical and chemical variables, which represent a key component of waterbody condition.<br>Chemical analysis can be used to identify the array of potentially important pollutants and their combinations.<br>Physical and chemical data collected at the same sites as biological information can be used to determine potential causes for any changes in biotic groups.<br>It is important to incorporate the two main sources of temporal variability of water quality including seasonal, episodic, yearly and diurnal variability. | Common measurements include temperature, pH, dissolved oxygen, biochemical oxygen demand, conductivity, turbidity, alkalinity/acidity, nutrient levels (phosphorus and nitrogen), total and suspended solids, ionic composition, hardness and odor, as well as hydrocarbons, metals, pesticides and other organic pollutants. | Parameters can be compared to the ASWQG and the CWQG.<br>General common water quality indicators provide a reliable measure of discharges that cause broad-scale impacts in the aquatic ecosystems.<br>For example, total phosphorus concentration is a measure of the phosphorus contribution to the aquatic ecosystem. Biological oxygen demand is used as an indicator of the carbon loading. Any changes in the concentration of suspended solids and water turbidity are an indication of aquatic ecosystem health. | Diagnostic |
| Sediment Quality | Sediments are habitats, food sources and refuges for many biological communities. They may influence surface water quality and can act as a source of contaminants to benthic organisms and potentially to the aquatic food chain.<br>Physical and chemical sediment analysis may help to identify sources of pollutants. | Common measurements include nutrients, metals, pesticides and trace organics. Particle size and organic content can influence concentration of contaminants.<br>Parameters can be compared to the CSQG. | Sediment data are important in assessing surface water trends because they provide historical information on the nature of conditions existing before various forms of human disturbance occurred in the area.<br>Trace metal concentrations in sediment should be used as indicators of impact in areas identified as under threat from specific localized activities. | Diagnostic |
| Phytoplankton | Phytoplankton can be used as an indicator of ecosystem health because it is one of the earliest assemblages to respond to chemical stresses, including acidification, nutrient enrichment, copper, oil and pesticide contamination.<br>They are particularly suitable for investigations involving organic and inorganic nutrients. | Parameters assessed include biomass (routinely used in biomonitoring of lakes and slow moving rivers), chlorophyll *a*, species diversity, abundance, composition, dominance and photosynthesis rate. | Sampling is easy, inexpensive, requires few people and creates minimal impact on resident biota.<br>Phytoplankton have cumulatively short life cycles and rapid reproduction rates.<br>Phytoplankton communities are at the base of the trophic chain.<br>Phytoplankton are very sensitive to various levels of metals. | Early Warning |
| Zooplankton | Zooplankton, as well as phytoplankton, responds to all types of disturbances and toxicants, therefore being a good indicator of ecosystem health.<br>Zooplankton populations are subject to extensive seasonal fluctuations reflecting changes in the ecosystems. They are a very important link between planktonic primary producers and higher carnivores, and are also early indicators of trophic shifts in the aquatic ecosystem. | Parameters assessed include biomass, composition, abundance and dominance. | Sampling is easy, inexpensive, requires few people and creates minimal impact on resident biota.<br>Zooplankton are a quick response indicator to water quality perturbation.<br>Zooplankton sorting and identification is fairly easy, in comparison to phytoplankton.<br>Zooplankton are very sensitive to a wide range of pollutants. | Early Warning |

**Table 3. (concluded)**

| Technique | Description | Parameters Assessed | Evaluation | Indicator Type |
|---|---|---|---|---|
| Periphyton and Macrophytes | Periphyton biomass is routinely used in biomonitoring shallower rivers and their growth rates are widely used to measure and monitor enrichment. Also provides the option of sampling the natural substrate of the stream or placing artificial substrates for colonization.<br>Macrophytes (aquatic plants) respond to nutrients, light, toxic contaminants (i.e., many species are sensitive to phytotoxins such as copper and herbicides), salt and management. Macrophytes respond more slowly to environmental changes than do phytoplankton or zooplankton and might be better integrators of overall environmental conditions. | Periphyton parameters assessed include species richness, total number of genera, total number of divisions, diversity indices for diatoms, biomass used in biomonitoring of shallow rivers, chlorophyll *a* and autotrophic index (ratio of total organic matter / autotrophic biomass (chlorophyll *a*) in periphyton).<br>Macrophyte parameters assessed include species identification and total area covered and percent cover (density) using aerial photography or field transects. | Sampling is easy, inexpensive, requires few people and creates minimal impact on resident biota.<br>Periphyton generally have rapid reproduction rates; very short life cycles and are valuable indicators of short-tem impacts.<br>Periphyton, as primary producers, are directly affected by physical and chemical factors.<br>Periphyton are good indicators of local conditions.<br>Relatively standard methods exist for the evaluation of periphyton (biomass, chlorophyll).<br>Periphyton are sensitive to some pollutants such as herbicides, which may not affect other communities.<br>Macrophytes respond to nutrients, turbidity/light, metals, herbicides and water level changes.<br>Macrophytes respond more slowly to environmental changes and therefore, can be integrators of environmental conditions. | Early Warning |
| Benthic Macroinvertebrates | Benthic macroinvertebrates are the organisms most commonly used for biological monitoring mostly because they are found in most habitats.<br>Aquatic macroinvertebrates can be used to evaluate the environmental condition of rivers, streams, lakes, ponds or wetlands. They help to identify sources and causes of impairment.<br>A macroinvertebrate survey should be accompanied by an assessment of habitat and water quality variables. | Parameters assessed include richness (total taxonomic richness), richness of taxonomic groups such as Ephemeroptera, Plecoptera, Trichoptera (EPT), abundance, diversity and evenness indices, composition (% of taxonomic groups, % of tolerant and intolerant groups) and tolerance indices. | Sampling is relatively easy, requires few people and inexpensive gear and it has minimal effect on the resident biota.<br>Macroinvertebrates are good indicators of localized conditions and they integrate the effects of short-term environmental variations.<br>Macroinvertebrates are relatively easy to identify to family; many intolerant taxa can be identified to lower taxonomic levels.<br>Macroinvertebrates comprise species that constitute different trophic levels and pollution tolerances that provide information on cumulative effects. | Early Warning |
| Fish | Fish can be use in bioassessment of water quality.<br>Fish populations and communities can respond actively to changes in water quality, but are also influenced by changes in hydrology and physical habitat structure (also true for above mentioned non-fish biota).<br>Fishes can move away when they detect pollution or habitat degradation in the water environment. | Parameters assessed include total number of species, number and identity of species, abundance and age class distribution, proportion of individuals as hybrids, proportion of individuals with disease, tumors, fin damage, and skeletal anomalies, total fish biomass and trophic composition. | Fish are good indicators of long-term effects and broad habitat conditions.<br>Fish assemblage includes a range of species that represent different trophic levels.<br>Fish are at the top of the aquatic food web.<br>Fish are relatively easy to collect and identify to the species level. | Compliance |

ASWQG Alberta Surface Water Quality Guidelines
CWQG Canadian Water Quality Guidelines
CSQG Canadian Sediment Quality Guidelines

hydraulic and water quality engineering, and empirically derived habitat (channel shape, water depth, velocity and substrate) versus flow functions (Maddock 1999).

Riparian health assessments for streams, lakes and wetlands examine vegetation and physical parameters that can provide information on the functioning of these areas (Cows and Fish 2005c). Parameters assessed include vegetation (plant community and structure), soil and hydrology.

### 4.3.2 Water Quality

Physical and chemical water quality represents a key component of waterbody health condition (USEPA n.d.). Chemical analysis can be used to identify the array of potentially important pollutants. It is important to incorporate temporal variability of water quality, including seasonal and episodic (Liston and Maher 1997), and diurnal and yearly variability into water quality assessments. Physical and chemical data collected at the same sites as biological information can be used to determine potential causes for any changes in biotic groups (Parsons *et al.* 2002).

Water quality can be described by measurements of standard parameters such as temperature, conductivity, dissolved oxygen (DO), pH, turbidity, light attenuation profiles, odor, biochemical oxygen demand (BOD), nutrients (phosphorus and nitrogen), total and suspended solids, ionic composition, hardness, metals and pesticides (Liston and Maher 1997). The most recommended parameters are conductivity, total phosphorus, BOD, turbidity and suspended solids which provide a measure of point source discharges that cause broad-scale impacts. Water quality parameters can be compared to the Alberta Surface Water Quality Guidelines (ASWQG) (Alberta Environment 1999) and the Canadian Water Quality Guidelines (CWQG) for the protection of aquatic life (CCME 1999).

Conductivity, which can be measured reliably and quickly, is an appropriate indicator of water column change and potential impact. Total phosphorus is an indicator of aquatic ecosystem health because it provides a robust, reliable measure of nutrient contribution to aquatic ecosystems. BOD can be used as an indicator of the loading of readily accessible carbon to aquatic ecosystems. Any changes in water turbidity can affect the entire trophic chain of any ecosystem. The alteration in the concentration of suspended solids is an indication of potential impact resulting from land uses and activities, providing a good indicator of ecosystem health. Although a standard suite of water quality indicators can be monitored to assess general water quality conditions, such a suite may need to be augmented by monitoring of water quality indicators that are relevant to local or regional issues.

Recently concerns about environmental contaminants has widened to include pharmaceuticals and personal care products (PPCP) (Boston University of Public Health 2002), brominated flame retardants (Birnbaum and Staskal 2004), pesticides and various endocrine disrupting substances which may emerge as important indicators of water quality and ecosystem health. These chemicals are constantly entering the environment, resulting in long-term exposure for the aquatic ecosystem and little is known about the effects or toxicology of these compounds.

The advantages of water quality sampling are:

- Water quality sampling is well standardized, with accepted sampling methods and protocols.
- Water quality is used to identify significant sources of chemical parameters.
- Many jurisdictions have an extensive historical, database which can be used to determine whether water quality degradation has occurred spatially or temporally.
- Comparisons to regulatory guidelines are available for several parameters and violations of these guidelines may be quantified.

Disadvantages of water quality sampling are:

- Multiple sampling over a period of time is required to identify statistical trends in water quality due to the variability in the data.
- Several sampling locations may be required to determine the actual cause or source of water quality degradation.
- Water quality exceedences over guidelines may not necessarily identify the causes and sources of degradation.
- Water quality exceedences over guidelines may occur only briefly at certain times and long-term impacts on the aquatic community may be difficult to predict.
- There are a limited number of guidelines against which water quality parameters can be compared.

### 4.3.3 Sediment Quality

Sediment may act as long-term reservoirs of chemicals to the aquatic environment and to organisms living in or having direct contact with sediments (habitats, food sources and refuges). It may influence surface water quality and can act as a source of contaminants to benthic organisms and potentially to the aquatic food chain (Department of Environment and Heritage 2000a). High concentrations of some trace elements and pesticides in sediments can be toxic to aquatic organisms and may indicate contamination from domestic or industrial sources (EPA 1999). Sediment quality can be described by the analysis of physical and chemical variables that may identify sources of pollutants. Sediment data are important in assessing surface water trends because they provide historical information on the nature of conditions existing before various forms of human disturbance occurred in the area (Department of Environment and Heritage 2000b).

The most common parameters assessed to evaluate sediment quality are trace elements (metals and metalloids), organic compounds (pesticides, polychlorinated biphenyls, PAHs, organophosphates, and dioxins and furans) and nutrients (total nitrogen and phosphorus) (EPA 1999, CCME 1999). Measurement of pesticides in sediments provides a more realistic measure of the historical presence of these substances in the water column over time. Sediment quality

parameters can be compared to the Canadian Sediment Quality Guidelines (CSQG) for the protection of aquatic life (CCME 1999).

The advantages of sediment quality sampling are:

- Sediment quality sampling is well standardized, with accepted sampling methods and protocols.
- Sediment quality is used to identify significant sources of chemical parameters from nearby sources.
- Comparisons to regulatory guidelines are available for some parameters and violations of these guidelines may be quantified.

Disadvantages of sediment quality sampling are:

- Sediment sampling to identify chemical parameters is only useful for parameters that become adsorbed to sediment particles.
- Multiple sampling is required to identify statistical trends in sediment quality due to the variability in the data.
- Several sampling locations may be required to determine the actual cause or source of sediment quality degradation.
- Sediment quality may not identify the actual causes and sources of chemical degradation since various sources can contribute to the sediments.
- There are a very limited number of guidelines against which sediment quality parameters can be compared.

### 4.3.4 Phytoplankton

Phytoplankton have rapid turnover times and are sensitive indicators of environmental stresses or changes (USEPA 2003). They are affected by physical, chemical and biological factors, making them valuable in monitoring programs (Findlay and King *al.* n.d.), especially in lentic waters (lakes and reservoirs) and slow flowing rivers and streams.

The phytoplankton community can provide an indication of nutrient enrichment in aquatic environments involving organic and inorganic nutrients (Department of Environment and Heritage 2000b). Changes in nutrient concentrations can result in long-term changes in assemblage structure and function and planktonic primary producers are one of the earliest assemblages to respond (USEPA n.d.). Phytoplankton has been shown to be sensitive to various levels of metals such as cadmium, copper, lead, mercury, manganese and zinc (St-Cyr *et al.* 1997).

The indicators that can be used include phytoplankton cell size and biomass, and species diversity (Xu *et al.* 2001). Phytoplankton biomass is routinely used in biomonitoring of lakes, estuaries and slow moving or impounded rivers (Department of Environment and Heritage

2000b). Chlorophyll *a* concentration is commonly used as an analog for phytoplankton biomass and is an indicator of elevated nutrient inputs.

Several advantages for the use of phytoplankton in biomonitoring programs are as follows:

- Sampling is easy, inexpensive, requires few people and creates minimal impact on resident biota.
- Phytoplankton have cumulatively short life cycles and rapid reproduction rates.
- Phytoplankton communities are at the base of the trophic chain occupying a fundamental role in ecosystem functioning.
- Phytoplankton are very sensitive to various levels of metals such as cadmium, copper, lead, mercury, manganese and zinc.

Disadvantage for the use of phytoplankton are as follows:

- Phytoplankton may have limitations due to their transient nature and variable spatial and temporal distribution of species.
- Indicator populations are often highly seasonal in nature.
- Phytoplankton require taxonomic expertise for species identification and fairly sophisticated laboratory work to quantify analysis.
- Phytoplankton have short lifespans which are not suited for long-term monitoring.

### 4.3.5 Zooplankton

Zooplankton populations are subject to extensive seasonal fluctuations reflecting changes such as hydrologic processes, recruitment and temperature (USEPA 2003). They are very important as a link between primary producers and higher carnivores and therefore are also early indicators of trophic shifts in the aquatic ecosystem (Gibson *et al.* 1996). The potential for using zooplankton as biological indicators and for long-term monitoring is best in lentic waters (lakes and reservoirs) and slow-flowing rivers and streams where they may be present in abundance (Norris and Norris 1995, Paterson n.d.).

Zooplankton are noted to be very sensitive to a wide range of pollutants. Changes in their abundance, diversity or composition can provide important indications of environmental change or disturbances, including nutrient loading, acidification, contaminants and sediment inputs, as well as pH, temperature, oxygen, salinity and food availability (Paterson n.d.).

Zooplankton indicators that can be used are composition, taxa richness, dominance, abundance, zooplankton body size and biomass, species diversity, macro- and micro-zooplankton biomass, the zooplankton phytoplankton ratio, and the macrozooplankton / microzooplankton ratio (Xu *et al.* 2001, USEPA n.d.).

The advantages of zooplankton sampling are similar to phytoplankton and include the following (Gibson *et al.* 1996):

- Zooplankton are a quick response indicator to water quality perturbation.
- Sampling is easy, inexpensive, requires few people and creates minimal impact on resident biota.
- Zooplankton sorting and identification is fairly easy, in comparison to phytoplankton,
- Zooplankton are very sensitive to a wide range of pollutants.

Disadvantage for the use of zooplankton are as follows:

- Zooplankton may have limitations due to their transient nature and variable spatial and temporal distribution of species.
- Zooplankton's response to stressors and impacts are not well documented.
- Zooplankton require taxonomic expertise for species identification but are easier to identify than phytoplankton.
- Zooplankton structure and function are controlled by both higher and lower trophic levels (fish predators and algal food).

### 4.3.6 Periphyton and Macrophytes

Periphyton (algae) communities are typically described in terms of numerical abundance, species composition, biomass (Scrimgeour and Kendall 1999) or chlorophyll *a*. Periphyton biomass is routinely used in biomonitoring shallower rivers and their growth rates are widely used to measure and monitor enrichment (Department of Environment and Heritage 2000b). Periphyton sampling can occur on natural substrates or by placing artificial substrates for colonization (Barbour *et al.* 1999). Metrics to analyze periphyton communities are species richness, total number of genera and divisions, diversity indices for diatoms, percent community similarity of diatoms and pollution tolerance index for diatoms (Barbour *et al.* 1999).

The advantages of using periphyton for aquatic ecosystem monitoring are:

- Periphyton generally have rapid reproduction rates, very short life cycles and are valuable indicators of short-term impacts.
- As primary producers, periphyton are more directly affected by physical and chemical factors.
- Sampling is easy, inexpensive, requires few people and creates minimal impact to resident biota.
- Relatively standard methods exist for evaluation such as biomass and chlorophyll measurements.
- Periphyton are sensitive to some pollutants, which may not affect other communities or may only affect other organisms at higher concentrations (e.g., herbicides).

Disadvantage of using periphyton are:

- Periphyton abundance and species composition may be variable due to local spatial variability from differences in water quality and substrate, as well as seasonal succession.
- Periphyton have been successfully used in streams but their application as lake indicators is relatively new.
- Periphyton's response to stressors and impacts, other than nutrient enrichment, are not well documented.

Macrophytes (aquatic plants) respond to nutrients, light, toxic contaminants (i.e., many species are sensitive to phytotoxins such as copper and herbicides), salt and management (USEPA 2003). A lack of macrophytes might indicate water quality problems due to herbicides, salinization or excessive turbidity, while an overabundance of macrophytes can be an indicator of excess nutrients. Exotic species (e.g., Eurasian water milfoil) often become dominant and cause problems under eutrophic conditions (USEPA 2003). Submerged macrophytes are often extensively managed. Attempts to control macrophyte growth include harvesting, herbicides and grass carp when they are thought to interfere with recreation or other use of the waterbody.

Macrophytes respond more slowly to environmental changes than do phytoplankton or zooplankton and might be better integrators of overall environmental conditions (USEPA 2003). This would allow a single sampling event per year, during the time of maximum abundance of macrophytes. Both floating leaved and emergent plants are easily assessed from aerial photographs, which permit estimates of total area covered and percent cover (density) within stands. Extent and percent cover of macrophytes, including submergent plants, can also be easily obtained from field surveys. The extent and percent cover of macrophytes can provide an assessment of the overall integrity of the lake or wetland system.

The advantages of using macrophytes for aquatic ecosystem monitoring are:

- Macrophytes respond to nutrients, turbidity/light, metals, herbicides and water level changes.
- Macrophytes respond more slowly to environmental changes and therefore, can be integrators of environmental conditions.
- Macrophytes are relatively easily sampled using either aerial photography or field transects to provide abundance metrics.

Disadvantage of using macrophytes are:

- Macrophytes occur only in slow moving or standing waterbodies and wetlands.
- Macrophyte assemblages are affected by temporal variability and are usually at maximum cover and extent in midsummer.
- Macrophyte's response to contaminants such as metals, organics and salinity are not well documented.
- Macrophytes are subject to management, through being planted or removed.

### 4.3.7 Benthic Macroinvertebrates

Benthic macroinvertebrates are the organisms most commonly used for biological monitoring, mostly because they are found in most habitats and there is extensive background knowledge available for these organisms. Many forms live in sediment and because of this, the resident community or representative taxa are the most common choice in assessment of sediment toxicity (Rosenberg *et al.* 2001, Department of Environment and Heritage 2000b, USEPA 2003).

Information about benthic macroinvertebrates preferred habitat and tolerance to certain types of pollution are used to interpret the environmental condition of a waterbody. There are some approaches that use benthic macroinvertebrate information as the basis upon which to assess the biological river health (Plafkin *et al.* 1989). The presence or absence of specific species provides information about water quality. Also the number of species (diversity), the number of organisms (abundance) and the relationship between all organisms present (community structure) can provide information about the health of the ecosystem (EPA 2002; EPA 2000a; EPA 2000b and EPA 1998). A benthic macroinvertebrate survey is generally accompanied by an assessment of habitat and other water quality variables (Culp *et al.* n.d. and Barbour *et al.* 1999).

Biological metrics of macroinvertebrates which can be used to assess aquatic ecosystem health include metrics such as richness (taxonomic richness and various diversity indices), composition (% taxonomic groups such as Ephemeroptera, Plecoptera, Trichoptera - EPT) and tolerance indices. Taxonomic richness represents the overall diversity of a macroinvertebrate assemblage, while EPT is a measure of the taxa diversity of the general water quality pollution sensitive orders.

The advantages of using benthic macroinvertebrates in a biomonitoring program are:

- Macroinvertebrates are abundant in most waterbodies and possess a sedentary mode of life making them good representatives of local conditions.
- Macroinvertebrates integrate the effects of short and long-term environmental variations (depending on the life cycle stage).
- Macroinvertebrates are relatively easy to identify to family and many "intolerant" taxa can be identified to lower taxonomic levels (i.e., identification keys are available).
- The macroinvertebrate community have species that constitute different trophic levels and pollution tolerances, which provide information for interpreting cumulative effects.
- Sampling is relatively easy, requires few people and inexpensive gear and there is minimal detrimental effect on the resident biota.
- Many water quality agencies focus their monitoring on macroinvertebrates rather than fish. Many agencies already have background macroinvertebrate data.

The disadvantages of using benthic macroinvertebrates are:

- Macroinvertebrates can possess high spatial variability due to habitat dependence.

- Macroinvertebrates require taxonomic expertise for species identification (expertise depends on level of identification and taxonomic group).
- Processing samples (sorting, identification and counting) can be time consuming.
- Macroinvertebrate metrics are not as well developed in lakes as in streams.

### 4.3.8 Fish

Fish have considerable potential for use in the bioassessment of water quality in some locations (Karr *et al.* 1986, Barbour *et al.* 1999, Kachale 2000, Department of Environment and Heritage 2000b). Fish populations and communities can respond actively to changes in water quality, but are also strongly influenced by changes in hydrology and physical habitat structure (Gerhke 1992, Department of Environment and Heritage 2000b). The biological metrics for fish that can be useful in the evaluation of ecosystem health are total number of fish species, number and identity of species, number of individuals in samples, proportion of individuals as hybrids, total fish biomass, trophic composition, and proportion of individuals with disease, tumors, fin damage and skeletal anomalies (Ellis 1999, USEPA 2003).

The advantages of fish sampling are:

- Fish are good indicators of long-term effects and broad habitat conditions because they are relatively long-lived and mobile, although mobility can also be a disadvantage.
- Fish assemblage includes a range of species that represent different trophic levels. They tend to integrate effects of lower trophic levels.
- Fish are at the top of the aquatic food web making them important for assessing contamination.
- Fish are relatively easy to collect and identify to the species level.
- Environmental requirements of most fish are well known.

The disadvantages of fish sampling are:

- Fish sampling can be time consuming and expensive with high spatial variability of species and gear problems.
- Fish mobility can complicate the assessment of impacts on fish since their residency time in the area is unknown. Fish actively avoid harmful conditions.
- Quantitative sampling in lakes is not as reliable as in streams because of lake morphology, bottom types and gear efficiency.
- Fish populations are generally subject to management with stocking and angling impacts in some areas.
- Extensive sampling of fish species can affect populations.

## 4.4 EVALUATION OF AQUATIC MONITORING TECHNIQUES AND INDICATORS

Traditionally, water quality monitoring has focused on physical and chemical measurements. The use of other indicators, in addition and complementary to physical and chemical water quality monitoring can greatly enhance the assessment and management of aquatic ecosystems. Therefore, biological monitoring or biomonitoring is an important tool in assessing the condition of aquatic ecosystems.

Aquatic ecosystem health cannot be measured directly. The overall condition or health of aquatic ecosystems is determined by the interaction of all its physical, chemical and biological components. It is generally impossible to measure all of these components and therefore indicators are used instead. Indicators can be defined as characteristics of the environment that provide quantitative information on the condition of ecological resources, the magnitude of stress or the exposure of a biological component to stress (Thorton *et al.* 1992). Aquatic indicators can include ones of hydrology, physical habitat, riparian, water quality, sediment quality or aquatic biota. Indicators are usually selected on the basis of their ability to represent the overall status of the environment, permit the detection of trends through their sensitivity to a range of stresses, and be measured and interpreted relatively easily. The most integrative measures of ecosystem health usually focus on biological endpoints (Karr 1999).

The aim of indicators is to describe environmental conditions (Fraser 1999). Therefore, indicators should be:

- able to quantify and simplify complex environmental features (i.e., measurable),
- standardized,
- responsive to environmental change,
- scientifically valid,
- on an appropriate geographic scale,
- easy to interpret and understand,
- cost effective, and
- forward looking and predictive.

Aquatic life integrates the cumulative effects of different stressors such as excess nutrients, toxic chemicals, increased temperature and excessive sediment loading. Therefore, biomonitoring can measure the aggregated or cumulative impact of the stressors. Because biological communities respond to stresses over time, they provide information that more rapidly-changing water chemistry measurements or toxicity tests do not always produce. As such, biomonitoring provides a more reliable assessment of long-term biological changes in the condition of a waterbody. The central purpose of assessing biological condition of aquatic communities is to determine how well a waterbody supports aquatic life.

The development of comprehensive sampling programs in the United States (Plafkin *et al.* 1989), United Kingdom (Wright 1995) and Australia (Norris and Norris 1995, Norris and Thoms 1999) have used macroinvertebrates as indicators. There appears to be a general consensus that if macroinvertebrate assemblages indicate a healthy ecosystem, other values are likely to

be protected as well (Boulton 1999). No single indicator alone is best and a synthetic approach that adopts a group of relevant metrics may prove most effective at measuring ecosystem health including physical, chemical and biological variables.

The approach proposed for assessing aquatic ecosystem health is one of a tiered approach (Figure 2). Since considerable amounts of data exist in Alberta on water quality and to a lesser extent sediment quality monitoring, the chemical and physical variables can be assessed to determine areas of potentially poor ecosystem health. Once areas of concern are identified and the type of stressor identified, biomonitoring (using the most appropriate variables such as phytoplankton, zooplankton, periphyton and/or benthic invertebrates depending on the potential type of effect or a combination) can be conducted to further define the health of the ecosystem. If serious effects are found during the biomonitoring phase, monitoring of the fish population may be warranted to determine the extent of effect in the food chain.

Table 4 provides a summary of monitoring indicators and techniques, which can be used to assess the effect of various stressors on aquatic ecosystem health. These diagnostic or early warning indicators can be used to identify and quantify effects on aquatic ecosystem health over time. Indicators should be relevant to the issues of concern identified within a waterbody or watershed. The acceptance of the indicator/technique was based on the frequency of use by the scientific monitoring community. The frequency of use was estimated based on not frequent as <25%, semi-frequent as 25 – 75% and frequent as >75% of the studies may involve the indicators or techniques listed. The relative cost was a general qualitative estimate based on the cost/sample or where no sample is required, the intensity of labor for conducting the survey. The overall rating of the indicator/technique was based on a combination of the acceptance, expected effectiveness and relative cost (rated with a number from 1 – 7 with 1 indicating the best and 7 the poorest indicator/technique).

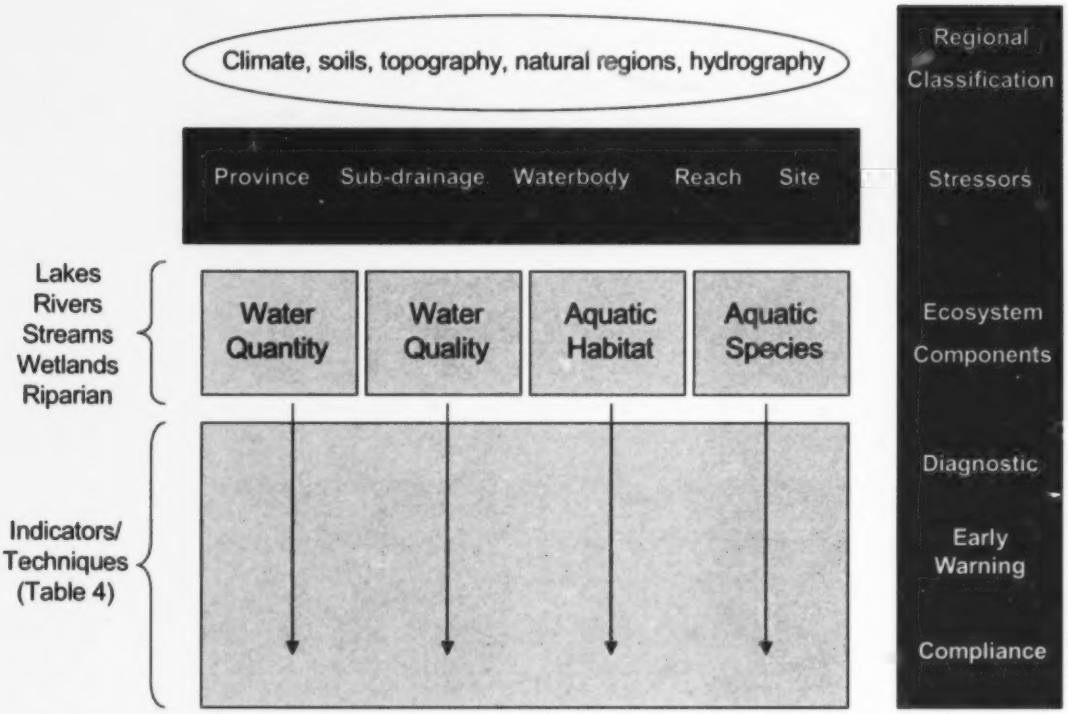


**Figure 2. Provincial and place-based approach to aquatic monitoring.**

**Table 4. Summary of monitoring indicators and techniques to assess the effects of various stressors on aquatic ecosystem health.**

| Specific Concerns or Stressors | Indicators and Techniques to Identify and Quantify Effects on Aquatic Ecosystem Health | Acceptance Based on Frequency of Use | Expected Effectiveness | Relative Cost | Rating |
|---|---|---|---|---|---|
| **Contaminant Loading** | | | | | |
| Pathogens | • Identification of pathogens in water and affected humans (such as giardiasis, botulism) (CWQG) | • Frequently | • Good | • High | • 3 |
| | • Identification of pathogens in water and waterfowl (based on mortalities in wetlands) (botulism) | • Not Frequently | • Medium | • High | • 6 |
| | • Identification of pathogens in water and amphibians (based on mortalities) (viral & fungal) | • Not Frequently | • Medium | • High | • 6 |
| Organic Pollutants/Oxygen Depleting Substances | • Water quality monitoring for organics (CWQG/ASWQG) | • Frequently | • Good | • Medium | • 2 |
| | • Dissolved oxygen monitoring (CWQG/ASWQG) | • Frequently | • Good | • Low | • 1 |
| Nutrients | • Water quality monitoring of nutrients (balance of N, P, DOC, ions) | • Frequently | • Good | • Low | • 1 |
| | • Organic influx (concentration of particulate organic matter) | • Semi-frequently | • Good | • Low | • 2 |
| | • Dissolved oxygen monitoring (CWQG/ASWQG) | • Frequently | • Good | • Low | • 1 |
| | • Algal blooms in lakes (phytoplankton chlorophyll *a*) | • Semi-frequently | • Good | • Low | • 2 |
| | • Algal blooms in lakes (phytoplankton identification for toxic species or monitoring of toxins of cyanobacteria) | • Semi-frequently | • Good | • Medium | • 3 |
| | • Periphytic algae in streams (chlorophyll *a* and ash free dry mass) | • Frequently | • Good | • Low | • 1 |
| | • Macrophytes (% coverage) | • Semi-frequently | • Good | • Low | • 2 |
| | • Zooplankton monitoring in lakes (biomass, composition, abundance and dominance) | • Not frequently | • Medium | • Medium | • 5 |
| | • Benthic macroinvertebrate monitoring (abundance, richness, tolerant/intolerant groups, trophic structure, and/or diversity, evenness and Bray-Curtis indices) | • Frequently | • Good | • Low | • 1 |
| | • Fish (condition factor, weight-at-age) | • Semi-frequently | • Medium | • Medium | • 4 |
| Sediments | • Water quality monitoring for suspended sediments (turbidity, secchi depth) | • Frequently | • Good | • Low | • 1 |
| | • Sediment quality monitoring of sediment bound contaminants such as metals (CSQG) | • Semi-frequently | • Good | • Medium | • 3 |
| | • Sediment deposition (particle size, rate of accumulation) | • Not Frequently | • Medium | • Low | • 3 |
| | • Physical habitat assessment (depth of pools) | • Not Frequently | • Medium | • Low | • 3 |
| | • Zooplankton monitoring in lakes (biomass, composition, abundance and dominance) | • Not Frequently | • Medium | • Medium | • 5 |
| | • Benthic macroinvertebrate monitoring (abundance, richness, tolerant/intolerant groups, trophic structure, and/or diversity, evenness and Bray-Curtis indices) | • Frequently | • Good | • Low | • 1 |
| Pesticides (includes insecticides, herbicides and fungicides)<br>(acute or chronic toxicity, endocrine disruption) | • Water quality monitoring for pesticides (CWQG) | • Semi-Frequently | • Good | • High | • 4 |
| | • Sediment quality monitoring for pesticides (CSQG) | • Not Frequently | • Good | • High | • 5 |
| | • Monitoring of aquatic vegetation loss from herbicides (% coverage) | • Not Frequently | • Medium | • Low | • 6 |
| | • Chronic toxicity testing | • Not Frequently | • Low | • High | • 7 |
| | • Benthic macroinvertebrates (abundance, richness, tolerant/intolerant groups, trophic structure, and/or diversity, evenness and Bray-Curtis indices) | • Not Frequently | • Medium | • Low | • 6 |
| | • Fish for endocrine disruption. | | | | |
| Metals<br>(chronic and acute toxicity, bioaccumulation) | • Water quality monitoring for metals (CWQG/ASWQG) | • Frequently | • Good | • Medium | • 2 |
| | • Sediment quality monitoring for metals (GSQG) | • Semi-frequently | • Good | • Medium | • 3 |
| | • Acute and chronic toxicity testing | • Not Frequently | • Medium | • High | • 6 |
| | • Fish tissue monitoring for metals (bioaccumulation) | • Semi-Frequently | • Good | • Medium | • 3 |
| Petroleum Hydrocarbons | • Water quality monitoring for hydrocarbons (CWQG) | • Frequently | • Good | • Medium | • 2 |

**Table 4. (continued)**

| Specific Concerns or Stressors | Indicators and Techniques to Identify and Quantify Effects on Aquatic Ecosystem Health | Acceptance Based on Frequency of Use | Expected Effectiveness | Relative Cost | Rating |
|---|---|---|---|---|---|
| Endocrine Disrupting Substances | • Monitoring for the presence of EDS | • Semi-frequently | • Medium | • High | • 5 |
| | • Laboratory bioassays to detect presence of EDS | • Not Frequently | • Poor | • High | • 7 |
| | • Monitoring of abnormalities in fish growth, development and reproduction (deformities, inhibited growth, decreased gonad weight, depressed thyroid and immune functions, sex ratios) | • Semi-frequently | • Medium | • High | • 5 |
| Wood Preservatives | • Water quality monitoring for wood preservatives (CWQG) | • Not Frequently | • Good | • Medium | • 4 |
| Pharmaceuticals and Personal Care Products | • Water quality monitoring for pharmaceuticals and PCPs | • Not Frequently | • Medium | • High | • 6 |
| | • Sediment quality monitoring for pharmaceuticals and PCPs | • Not Frequently | • Medium | • High | • 6 |
| Brominated Flame Retardants | • Water quality monitoring for BFRs | • Not Frequently | • Medium | • High | • 6 |
| | • Sediment quality monitoring for BFRs | • Not Frequently | • Medium | • High | • 6 |
| | • Air quality monitoring for BFRs | • Not Frequently | • Poor | • High | • 7 |
| Biosolids/Sludges | • Water quality monitoring for contaminants associated with biosolids/sludges in nearby surface waters (nutrients, metals, volatile organics) | • Semi-frequently | • Medium | • Medium | • 4 |
| | • Monitoring of contaminants (nutrients, metals and volatile organics) in biosolids/sludges | • Semi-frequently | • Good | • Medium | • 3 |
| **Landscape Changes/Habitat Alterations** | | | | | |
| Construction of Dams and Other Impoundments | • Hydrological assessment (effects on discharge) | • Frequently | • Good | • Medium | • 2 |
| | • Physical habitat assessment (habitat fragmentation, altered flows, dewatering of areas, flooding of areas) | • Frequently | • Good | • Low | • 1 |
| | • Restricted passage or movement of fish assessment | • Semi-frequently | • Medium | • Medium | • 4 |
| | • Water quality monitoring (nutrients, metals, temperature, dissolved oxygen) | • Semi-frequently | • Good | • Medium | • 3 |
| Disruption of Riparian Habitat | • Riparian habitat monitoring (vegetation species composition, structure in terms of ground cover, shrubs and overstory, width of riparian zone, proportion of native to "weed" species, extent of riparian clearing) | • Frequently | • Good | • Low | • 1 |
| | • Physical habitat assessment of waterbody due to streamside vegetation removal (bank stability, % shade lost, sedimentation) | • Semi-frequently | • Good | • Low | • 2 |
| Waterbody Habitat Alteration or Loss | • Physical habitat assessment (velocity, depth, morphological types, bank stability, % instream cover, substrate) | • Frequently | • Good | • Low | • 1 |
| Draining of Wetlands | • Loss or fragmentation of wetland area (% wetland lost) | • Semi-frequently | • Good | • Low | • 2 |
| | • Species at risk of habitat loss (% decrease in waterfowl, amphibians) | • Semi-frequently | • Good | • Medium | • 3 |
| Disturbance of Hydrologic Regime | • Instream flow needs assessment | • Not-frequently | • Good | • High | • 5 |
| | • Physical habitat assessment (loss of wetted area, widening of channel, discharge) | • Semi-frequently | • Good | • Low | • 2 |
| Vegetation Removal (agriculture, forestry, cut lines) | • % Cover and fragmentation of vegetation | • Semi-frequently | • Good | • Low | • 2 |
| | • Sediment deposition into waterbodies from erosion (particle size) | • Semi-frequently | • Good | • Low | • 2 |
| Changes in Chemical and Physical Process | • Water quality monitoring | • Semi-frequently | • Good | • Medium | • 3 |
| Intensification of Urbanization of Watersheds | • Water quality monitoring (various contaminants) | • Semi-frequently | • Good | • Medium | • 3 |
| | • Physical habitat assessment (sedimentation, loss of wetlands) | • Not frequently | • Good | • Low | • 2 |
| | • Landuse (type and extent of landuse) | • Semi-frequently | • Good | • Low | • 2 |
| **Water Use/Water Allocation** | | | | | |
| Population Growth - Increased Consumption (urban and agriculture) | • Instream flow needs assessment | • Not-frequently | • Good | • High | • 5 |
| | • Monitoring of water quality, riparian habitat and fish if instream flow needs are not met | • Not-frequently | • Good | • High | • 5 |
| | • Monitoring discharge levels | • Frequently | • Good | • Medium | • 2 |

**Table 4. (continued)**

| Specific Concerns or Stressors | Indicators and Techniques to Identify and Quantify Effects on Aquatic Ecosystem Health | Acceptance Based on Frequency of Use | Expected Effectiveness | Relative Cost | Rating |
|---|---|---|---|---|---|
| Population Growth – Increased Stormwater Runoff | • Water quality monitoring (various contaminants) | • Semi-frequently | • Good | • Medium | • 3 |
| Change in Flow Regime (withdrawals) | • Instream flow needs assessment | • Not-frequently | • Good | • High | • 5 |
| | • Monitoring of water quality, riparian habitat and fish if instream flow needs are not meet | • Not-frequently | • Good | • High | • 5 |
| | • Monitoring discharge levels | • Frequently | • Good | • Medium | • 2 |
| **Air Emissions and Acidification** | | | | | |
| Industrial Air Pollution (dust and contaminants) | • Air quality monitoring (carbon dioxide, carbon monoxide, nitrogen oxide, ammonia, methane) | • Semi-frequently | • Good | • High | • 4 |
| Acid Inputs and Acid Rain | • Water chemistry (pH and alkalinity of lakes and ponds) | • Semi-frequently | • Good | • Low | • 2 |
| | • Precipitation (acid rain) | • Not Frequently | • Good | • Low | • 3 |
| | • Zooplankton in lakes (biomass, composition, abundance and dominance) | • Semi-frequently | • Medium | • Medium | • 4 |
| | • Monitor sensitive aquatic systems especially if there is a risk of exceeding threshold levels of acidifying emissions | • Not Frequently | • Good | • Low | • 3 |
| Vehicle Emissions (greenhouse gases) | • Air quality monitoring (carbon dioxide, methane) | • Semi-frequently | • Good | • High | • 4 |
| Atmospheric Deposition of Contaminants | • Monitor contaminants in wet and dry atmospheric deposition | • Semi-frequently | • Good | • High | • 4 |
| **Recreational Use** | | | | | |
| Water-Based Activities (swimming, boating, water skiing, camping) | • Water quality monitoring (pathogens, nutrients, hydrocarbons) | • Not Frequently | • Good | • High | • 5 |
| Habitat Alterations (beach modifications, marinas, docks, piers) | • Physical habitat assessment (substrate, shoreline erosion) | • Semi-frequently | • Good | • Low | • 2 |
| Fishing Pressure | • Creel surveys | • Not frequently | • Medium | • Medium | • 5 |
| | • Fish population surveys | • Semi-frequently | • Good | • High | • 4 |
| | • Population genetic structure using DNA (determine genetic variability to protect endangered species) | • Not frequently | • Poor | • High | • 7 |
| Access Management | • Monitoring road density (length of roads and trails) | • Not frequently | • Poor | • Medium | • 6 |
| | • Monitoring use of roads and trails (number of vehicles) | • Not frequently | • Medium | • Medium | • 5 |
| **Exotic Species** | | | | | |
| Exotic Species Introduction | • Presence/absence of exotic species | • Semi-frequently | • Good | • Medium | • 3 |
| | • Ratio of exotics to natural species | • Semi-frequently | • Good | • Medium | • 3 |
| **Transportation Infrastructure** | | | | | |
| Infrastructure Development (roads, bridges, culverts) | • Physical habitat assessment (sedimentation, fish habitat, spawning grounds) | • Frequently | • Good | • Low | • 1 |
| | • Fish presence/absence survey | • Frequently | • Good | • Medium | • 2 |
| Wetland Loss | • Loss or fragmentation of wetland area (% wetland lost) | • Semi-frequently | • Good | • Low | • 2 |
| | • Species at risk of habitat loss (% decrease in waterfowl, amphibians) | • Semi-frequently | • Good | • Medium | • 3 |
| Salinity (road salting) | • Water quality monitoring for salinity | • Not-frequently | • Good | • Low | • 3 |

**Table 4. (concluded)**

| Specific Concerns or Stressors | Indicators and Techniques to Identify and Quantify Effects on Aquatic Ecosystem Health | Acceptance Based on Frequency of Use | Expected Effectiveness | Relative Cost | Rating |
|---|---|---|---|---|---|
| **Natural Disturbances** | | | | | |
| Drought | • Precipitation, temperature and discharge monitoring | • Frequently | • Good | • Medium | • 2 |
| | • Benthic macroinvertebrate monitoring (abundance, richness, tolerant/intolerant groups, trophic structure, and/or diversity, evenness and Bray-Curtis indices) | • Not frequently | • Good | • Low | • 3 |
| | • Riparian habitat assessment | • Semi-frequently | • Good | • Low | • 2 |
| | • Some aspects of water quality (dissolved oxygen, temperature, conductivity, nutrients) | • Frequently | • Good | • Low | • 1 |
| Flooding | • Precipitation monitoring and discharge monitoring | • Frequently | • Good | • Medium | • 2 |
| | • Benthic macroinvertebrate monitoring (abundance, richness, tolerant/intolerant groups, trophic structure, and/or diversity, evenness and Bray-Curtis indices) | • Not frequently | • Good | • Low | • 3 |
| | • Riparian habitat assessment | • Semi-frequently | • Good | • Low | • 2 |
| | • Some aspects of water quality (dissolved oxygen, temperature, conductivity, nutrients) | • Frequently | • Good | • Low | • 1 |
| Wildfire | • Temperature and precipitation monitoring | • Frequently | • Good | • Medium | • 2 |
| | • Weather monitoring (lightning) | • Frequently | • Good | • Medium | • 2 |
| | • Benthic macroinvertebrate monitoring (abundance, richness, tolerant/intolerant groups, trophic structure, and/or diversity, evenness and Bray-Curtis indices) | • Not Frequently | • Good | • Low | • 3 |
| | • Some aspects of water quality (suspended solids, nutrients) | • Frequently | • Good | • Low | • 1 |
| **Climate Change** | | | | | |
| Streamflow and Lake Levels | • Instream flow needs survey | • Not Frequently | • Good | • High | • 5 |
| | • Monitoring lake levels | • Not Frequently | • Good | • Medium | • 4 |
| | • Zooplankton in lakes (biomass, composition, abundance and dominance) | • Not Frequently | • Medium | • Medium | • 5 |
| Extreme Weather Events | • Monitoring extent and duration of extreme weather events (heavy rain causing flooding, dry conditions causing drought ) | • Frequently | • Good | • Medium | • 2 |
| Changes in Chemical and Physical Process (temperature, precipitation, greenhouse gases) | • Ice phenology (lake ice duration, glaciers) | • Not Frequently | • Medium | • Medium | • 5 |
| | • Temperature and precipitation monitoring | • Frequently | • Good | • Medium | • 2 |
| | • Air quality monitoring (carbon dioxide, methane) | • Semi--frequently | • Good | • High | • 4 |

Note: Acceptance is based on the frequency of use of the method in the scientific monitoring community. The frequency of use was estimated based on not frequent as <25%, semi-frequent as 25 – 75% and frequent as >75% of the studies may involve the indicators or techniques listed.
Expected Effectiveness is rated as good, medium or poor.
Relative Cost is a qualitative estimate based on the cost/sample or where no sample is required, the intensity of labor for conducting the survey.
Rating is a value between 1 – 7 and is based on a combination of the acceptance, expected effectiveness and relative cost. A rating of 1 indicates that the indicator is frequently used, has a good expected effectiveness and has a low relative cost, while a rating of 7 indicates that it is not frequently used, has a poor expected effectiveness and a high relative cost.

ASWQG Alberta Surface Water Quality Guideline
CWQG Canadian Water Quality Guideline

# 5.0 Summary and Conclusions

A working definition of "aquatic ecosystem health" was developed mainly on the ideas that incorporate both ecological integrity and human values. *"A healthy ecosystem is sustainable and resilient to stress, maintaining its ecological structure and function over time similar to the natural (undisturbed) ecosystems of the region, with the ability to recover from disturbance, while continuing to meet social needs and expectations ".*

Issues of concern in Alberta include the effects of natural resources exploitation (coal mining, oil and gas, tar sands and forestry), water management and control structures (dams, reservoirs, dikes, diversions and weirs), industrial development (pulp mills, power plants, petrochemical industry and food processing), agriculture, population growth, recreation, transportation infrastructure, natural disturbances and climate change. Effects in aquatic ecosystems may not only directly affect aquatic organisms but may extend into semi-aquatic species. Similarly, effects are not solely related to biotic factors but may include abiotic effects that ultimately affect the aquatic ecosystem. These issues can be considered individually or more frequently in a synergistic or cumulative manner. One source may dominate over another but cumulatively they all may contribute to effects on receptors in the aquatic ecosystem.

The issues with the most number of potential effects from stressors, ranging from contaminants to habitat alteration, include natural resource exploitation, agriculture and population growth. These are followed by water management and control structures, industrial development, recreation and natural disturbances. The stressors with the highest severity, usually locally, are contaminant loading (mainly nutrients, sediment and metals), habitat alteration and water use effects. Little is known about the severity and extent of effects from EDS, pharmaceuticals and BFR. Air emissions effects are low in severity resulting mainly from natural resource exploitation and industrial development. Exotic species introductions and overharvesting of biota are local effects resulting from recreation.

Aquatic monitoring consists of three fundamental approaches which provide valuable indications of the overall health of the ecosystem including chemical, physical and biological measurements. Biological monitoring is a fundamental part of an ecologically-based approach and allows for the assessment of environmental health of the aquatic resources. Aquatic organisms act as natural monitors responding to their total environment including all types of disturbances and toxicants.

The approach proposed for assessing aquatic ecosystem health is one of a tiered approach. Since considerable amounts of data exist in Alberta on water quality and to a lesser extent sediment quality monitoring, the chemical and physical variables can be assessed to determine areas of potentially poor ecosystem health. Once areas of concern are identified and the type of stressor identified, biomonitoring (using the most appropriate variables such as phytoplankton, zooplankton, periphyton and/or benthic invertebrates depending on the potential type of effect or a combination) can be conducted to further define the health of the ecosystem. If serious effects are found during the biomonitoring phase, monitoring of the fish population may be warranted to determine the extent of effect in the food chain.

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## 7.0 Stantec Quality Management

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